Original Article

Low-carb Diet in Hospitalized Late Pubertal Type 1 Diabetic Girls: A Short-Term CGM Study

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Abstract

Objective: We conducted the present study to observe potential short-term benefits or risks of low-carb diet (LCD). **Methods:** This is a prospective randomized cross-over study. Type 1 diabetic girls were hospitalized in ternary groups for 7 days and each group randomly started with LCD or regular diet. Continuous glucose monitoring (CGM) was performed between 0 and 168 h. **Results:** Twenty-eight subjects completed the study. Total energy, protein, and fat consumption were high ($P < 0.001$); carbohydrate consumption and rapidly acting insulin dose were low ($P < 0.001$ and $P = 0.002$, respectively) during LCD. Morning postprandial, noon postprandial, and evening preprandial capillary blood sugar levels were lower during LCD ($P = 0.013$, 0.018, and 0.048, respectively). **Conclusion:** LCD may have the advantage of better glycemic control despite lower insulin dose which is a favorable outcome with regard to weight control and atherosclerosis prevention. No adverse events were observed.

Keywords: Continuous glucose monitoring, diet, low carbohydrate, puberty, type 1 diabetes

Introduction

The aim of type 1 diabetes management is the achievement of an overall health, longevity, and quality-of-life status comparable to those of healthy people. Reaching glycemic targets as good as possible is the main term, whereas Hemoglobin A1c (HbA1c) and glycemic variation are two main criteria for this. It is well known that complication rates drop by lowering HbA1c.[1] Hypoglycemia is not just a limiting factor for a better insulinization, but it is also the component of "high glycemic variability." High glycemic variability is a contributor to complications.[2] While the use of technology and newer drugs (insulin or add ons) help to reach the targets, nutrition therapy is still the main cornerstone of diabetes management. Lowering the carbohydrate ratio is reportedly a successful strategy in the management of obesity, type 2 diabetes, and type 1 diabetes.[3-5] There are few reports of small prospective studies in adults and observational studies in children about low-carb diet (LCD) in type 1 diabetic subjects, but controlled studies are lacking especially in pediatric and adolescent type 1 diabetic cases.[6-8] We conducted the present study to observe potential short-term benefits or risks of LCD in a subgroup of pediatric type 1 diabetic subjects, that is, adolescent girls.

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Methods

General study characteristics

This is a prospective randomized cross-over study conducted between April and July, 2016. Type 1 diabetic girls at puberty stage ≥3 according to Tanner were hospitalized in ternary groups. According to the random number table, each "trio" randomly started with LCD or regular diet (RD) and changed to the alternate diet during the second period. CGM (Dexcom Platinum G4) was performed between 0 and 168 h, either diet 12–72 or 108–168 h

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and washout period 72–108 h. Thus, the effect of sequence was tried to be eliminated by applying the cross-over design.

Inclusion criteria: The criteria were type 1 diabetes for at least 6 months of duration, being female, and at least at the third stage of puberty according to Tanner (Tanner stage 3–5), giving consent to participate in the study.

Exclusion criteria: Any severe diabetes complication, acute disease, or menstrual period during study days, other severe chronic conditions, and any medication except for insulin.

Sample size: To obtain a clinically and statistically significant difference with 5% significance level, 80% power, and 0.50 effect size, it was planned to randomly select at least 14 patients for each sequence in accordance with the study protocol. The sample size against patient loss was determined as 30 patients.

Ethics: The study was approved by the Duzce University Faculty of Medicine Ethics Committee on September 8, 2015 (2015/165). Informed written consent was obtained from every subject and at least one legal guardian.

Study design

Type 1 diabetic girls attending the outpatient clinic for routine control and those selected from the patient list were revised for eligibility using electronic files. Selected cases were invited to the study by direct interview or phone call. A single room in the pediatric ward was organized for the study. It was a three-bedroom with a refrigerator, a digital kitchen scale (King®) sensitive to 1 g, and posters on the wall with nutrition facts of several foods. According to their availability, subjects were grouped as three girls for each week. Random numbers served to choose with which kind of diet to start for the corresponding "trio" (trio: the three diabetic girls who stay together during the same week in the same room and applying the same order of diets). All subjects who started with LCD and after wash-out (WO) period changed to RD were called group 1 and vice versa group 2. Hospitalization started every Sunday afternoon and ended the other Sunday after 07:00 p.m.

Glucose monitoring

Dexcom Platinum G4 was inserted every Sunday at 07:00 p.m. to each subject. Sensors [Mean absolute realtive difference (MARD) 13.5%, glucose measuring range 2.2–22.2 mmol/L (40–400 mg/dL)] were applied to abdomen and this site was not used for insulin injections. CGM monitorization was started after a 12-h equilibrium period, that is, on Monday 07:00 a.m. Concomitant capillary glucose monitoring was started and at least eight measurements were made each day before and 2 h after meals, at bedtime, and at night (03:00, 07:00, 09:00, 11:30 a.m., 01:30, 05:00, 07:00, 12:00 p.m.). More capillary measurements were made when necessary. Optium Xceed glucometer and FreeStyle Optium Blood Glucose Test Strips® (Abbot) belonging to the hospital were used in common. Calibration of CGM was made at 07:00 a.m., 05:00 p.m., and 22:00 p.m.

When setting glycemic ranges for continuous glucose monitoring system (CGMS), low blood sugar was defined as <4.4 mmol/L (<80 mg/dL), target range as 4.4–7.2 mmol/L (80–130 mg/dL), and high blood sugar as >7.2 mmol/L (>130 mg/dL). Daily 240 measurements of CGMS were evaluated as the ratio of each abovementioned group to total in percentages.

Insulin therapy

Subjects continued with their usual regimen. Basal dose was adjusted according to capillary blood sugars at 03:00 and 07:00 a.m. every day. For subjects who are not counting carbs, prandial dose was advised to be decreased by 25% during the first injection in the LCD period and thereafter adjustments were made according to 2-h postprandial blood sugars. Protein counting but not fat counting was advised to carb-counting subjects. CGM was not taken into account during insulin adjustment. During hypoglycemia, however, the arrow indicators were used to decide on the intervention together with extracapillary measurements and subjective symptoms. Insulin injections were supervised by ward nurses and the exact time was recorded.

Diets

Before the start of the study, we prepared fixed menus for the subjects. Meals were prepared in the kitchen of the hospital according to the list, thereafter weighed and packed by the responsible food technician. They contained 2000 kcal/day, 25% and 55% of energy coming from carbohydrates for LCD and RD periods, respectively. But soon after the beginning with the first group, we noticed that we could not achieve the expected compliance. So we gave up using the strict prepared menus. We decided to advise the subjects in general how to eat during periods, asked them to follow the instructions as much as possible and motivated them telling that this experience would help them in the future to choose the right nutrition pattern to keep the blood sugars well and control their weight. Subjects consumed foods given by the hospital as much as they like, they were allowed to buy extra foods with nutrition facts labels from the surrounding facilities.

They were asked to comply strictly with the meal times on the other hand. Our intention was to analyze the daily macronutrient consumption later. Detailed records of food consumption were kept under the supervision of the study team as well as the ward nurses. Every eaten item should be weighed before or labels read in packaged foods.

During RD subjects were asked to consume at least two and one portions of starchy and/or sugary foods in meals and snacks, respectively, one portion of protein-rich food in every meal, and not to add extra "visible" fats and oils other than that used during preparation of the meals. During LCD, subjects were asked to not consume starchy and sugary foods. They were told to add olive oil to salads or vegetable meals and butter at breakfast and eat nuts, olives, cheese, yogurt, or processed meat at snacks. The study team provided the extra items especially for the LCD period and fresh vegetables like

cucumber and tomatoes and taste enhancers like spices and sauces for each period.

The macronutrient analysis was made using the official website TURCOMP,[9] where a detailed report for every food including elementary components like fatty- and amino acid profiles, vitamins, and minerals is available if one enters the sort and quantity of any food.

During hypoglycemia, subjects consumed standard 10 g of sugar which should be added to the daily consumption list.

Periods of the study

The whole study period lasted 168 h. First 12 h served as an equilibrium of CGM, the coming 60 h as the first diet period, 36 h thereafter, that is, washout period was the "free eating" period, and the last 60 h was for the alternate dieting period. Both dieting periods comprised three main meals and three snacks.

Other data collected for the study

In the first morning of hospitalization, the subject's height, weight, and blood pressure were measured. Height was measured using Harpenden stadiometer and weight using SECA 764 scale sensitive to 100 g with light clotting. Fasting venous blood was obtained for HbA1c, blood count, and biochemistry (skipped if measured during last month). Capillary β-OH butyrate measurement was made and repeated at the end of first dieting period, and at the beginning and end of the second dieting period using Optimum Xceed glucometer and FreeStyle Optium blood β-Ketone test strips® (Abbot).

Statistical analysis

Subjects who started the study with LCD and after WO period applied RD were called the first group and the contrary the second group. Comparisons were made with respect to the two diet periods as well as to the two groups. Descriptive statistics of all data were performed. The normal distribution of the variables was checked by Shapiro–Wilk's test. Group differences were analyzed using independent samples *t*-test and Mann–Whitney's *U* test. For the intergroup comparisons of continuous variables, 2 × 2 crossover design analysis was applied.

Results

A total of 10 "trio's" including 30 subjects were recruited to the study. Two subjects were eliminated around the middle of their study weeks, occasionally one from each group. One of them was discarded because of diet incompliance and one gave up related to psychological intolerance to stay in the hospital. The remaining 28 subjects were analyzed [Figure 1].

General characteristics of the subjects are summarized in Table 1; anthropometry and metabolic indices were slightly worse in the second group, which were slightly significant just for triglycerides and AST at entry.

All subjects were using basal-bolus insulin regimen and short- and long-acting insulin analogs (combinations of aspart, lispro, glargin, and detemir).

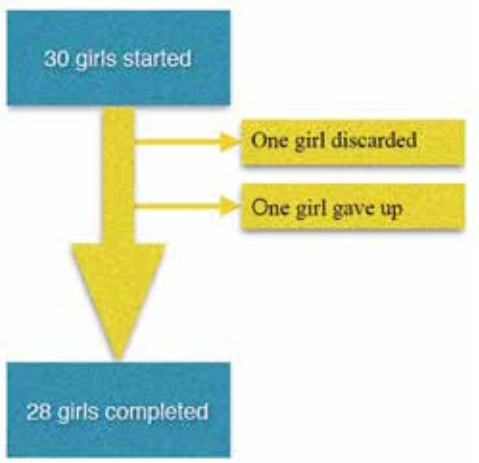

Figure 1: Flow diagram of the study population

Daily requirement of insulin was 0.21–1.81 IU/kg for the whole period. Prandial insulin dosage during LCD, WO, and RD was respectively (20 ± 11.7), (34.7 ± 15.7), (25.4 ± 10.9) for treatment affect ($P = 0.002$). Prandial dose was significantly lower in LCD, whereas basal dose was slightly higher during LCD and this was not affected by the order of diet periods [Table 2 and Figure 2a, b].

Regarding capillary β-OH-butyrate controls, no elevation or period differences were observed ($P = 1.00$).

Subjects consumed higher energy during LCD [1811.48 vs. 1577.35 kcal/day ($P < 0.001$)]. Mean macronutrient composition in grams and percentage of total energy during LCD and RD was 112.36 (24) vs. 196.37 (49) for carbohydrates, 104.24 (51) vs. 49.80 (28) for fats, and 94.36 (25) vs. 75.71 (19) for proteins, respectively ($P < 0.001$ for all comparisons). This difference was not affected by the order of diet periods [Figure 3a-d].

Evaluation of CGMS reports and capillary blood glucose measurements: CGMS data revealed nearly same low percentage and slightly better target percentage, high percentage as well as average glucose and standard deviation during LCD though none of them were significant [Table 3]. Capillary measurements on the other hand revealed advantageous results during LCD in morning postprandial, noon preprandial, and evening preprandial glycemia, which were significant, and in noon and evening postprandial glycemia, which were nonsignificant. Morning preprandial and midnight capillary glycemia were slightly but nonsignificantly higher during LCD [Table 3].

Discussion

Since years, the recommended macronutrient composition for healthy people as well as diabetic subjects has been similar and can be summarized as a "normocaloric" diet with a 50–60% contribution of carbohydrates to the total daily energy consumption.[10] Even in weight-loss programs is this ratio traditionally the same and limited total daily energy

Table 1: Characteristics of participants

	Group 1§ (*n*=14)	Group 2¶ (*n*=14)	Total (*n*=28)	*P*
Age (years)†	16.5±2.2	15.7±2	16.1±2.1	0.296
Weight (kg)†	62.1±15.9	62±13.8	62±14.6	0.994
Height (cm)†	158.6±6.2	157.3±4.6	158±5.4	0.539
BMI (kg/m^2)†	24.5±4.8	25.1±4.8	24.8±4.7	0.706
Waist circumference (cm)†	83.7±14.5	89.9±10.5	86.8±12.8	0.208
HbA1c (%)†	9.1±2.7	9.9±2	9.5±2.3	0.394
Diabetes duration (months)†	64.7±40	84.4±41.7	74.5±41.3	0.215
Total cholesterol (mmol/L)†	4.5±1.0	5.0±1.5	4.7±1.2	0.482
Triglycerides (mmol/L)†	1.0±0.5	1.8±0.8	1.4±0.7	**0.004**
HDL (mmol/L)†	1.6±0.5	1.5±0.4	1.5±0.4	0.378
LDL (mmol/L)†	2.3±0.6	2.7±1.1	2.5±0.9	0.379
ALT (mg/dL)‡	11.1 (2.6)	15.1 (13.1)	11.8 (5.9)	0.085
AST (mg/dL)‡	13.5 (6)	19.6 (21.4)	16.1 (11.9)	**0.039**
Systolic blood pressure (mmHg)‡	111 (20)	113 (15)	111 (11)	0.246
Diastolic blood pressure (mmHg)‡	70 (13)	70 (11)	70 (12)	0.910

HDL=High-density lipoprotein, LDL=Low-density lipoprotein, ALT=Alanine aminotransferase, AST=Aspartate Aminotransferase, BMI=Body mass index. †Mean±standard deviation ‡Median (interquartile range). §Subjects who started with low-carb diet and changed to regular diet after washout period. ¶Subjects who started with regular diet and changed to low-carb diet after washout period

Table 2: Insulin dosage during the low-carb diet, regular diet, and washout periods

		Prandial insulin dose (IU/day)			
	Number of subjects	Low-carb diet	Washout period	Regular diet	*P*
Number of subjects		14	14	14	
Group 1§	14	15.5±8.6†	27.6±15.8†	21.8±11.8†	**0.002***
Group 2¶	14	24.5±13†	41.8±12.5†	29±10.1†	0.557**
All	28	20±11.7†	34.7±15.7†	25.4±10.9†	0.050***
		Basal insulin dose (IU/day)			
Number of subjects		14	14	14	
Group 1§	14	24.3±13.2†	20.9±10.9†	23.1±13†	**0.013***
Group 2¶	14	25.8±11.1†	26.3±11.4†	25±11.8†	0.592**
All	28	25±12†	23.6±11.3†	24.7±11.9†	0.717***

†Mean±Standard Deviation. §Subjects who started with low-carb diet and changed to regular diet after washout period. ¶Subjects who started with regular diet and changed to low-carb diet after washout period. *Treatment effect. **Period effect. ***Carryover effect

Table 3: Comparison of glycemia during two diet periods (mean±SD)

	Low-carb diet	Washout period	Regular diet	*P*
CGMS data				
Low blood sugar (%)	0.07±0.07	0.07±0.1	0.06±0.06	0.297
In target blood sugar (%)	0.23±0.1	0.2±0.2	0.19±0.1	0.186
High blood sugar (%)	0.7±0.2	0.74±0.2	0.75±0.2	0.185
Average glucose mmol/L (mg/dL)	9.8±1.9 (177.1±34.7)	10.4±2.4 (188.1±43.5)	10.3±1.6 (186.9±29)	0.117
Standard deviation	58.5±17.7	61.6±12.1	61.8±14	0.328
Capillary BG measurements mmol/L (mg/dL)				
Morning preprandial	10.2±3.7 (184.8±67.9)	10.1±4.3 (184.2±78.8)	10.2±3.0 (183.8±55.8)	0.870
Morning postprandial	9.1±2.8 (164.8±51.5)	13.4±4.8 (241.5±88)	10.8±2.6 (195.8±47.9)	**0.013**
Noon preprandial	10.0±2.7 (180.4±48.8)	11.6±3.9 (210.4±71.6)	11.1±2.5 (201.7±46)	**0.018**
Noon postprandial	8.0±2.9 (145.3±53.8)	11.1±5.2 (201.7±94.2)	7.5±1.9 (135.5±35.8)	0.624
Evening preprandial	8.9±3.2 (161±58.8)	11.6±4.3 (209.9±79.1)	9.7±3.0 (174.9±55.7)	**0.048**
Evening postprandial	10.0±3.3 (181.4±61.1)	10.2±4.1 (183.9±74.3)	11.1±3.3 (200.8±60.9)	0.164
Bedtime	11.0±3.0 (198.6±55.3)	11.9±3.8 (214.6±70)	11.6±2.7 (210.3±50.3)	0.351
Midnight (03:00)	9.5±3.0 (173.8±54.5)	10.8±3.6 (194.9±66)	8.8±2.5 (159.6±46.2)	0.247

CGMS=continuous glucose monitoring system, BG=blood glucose

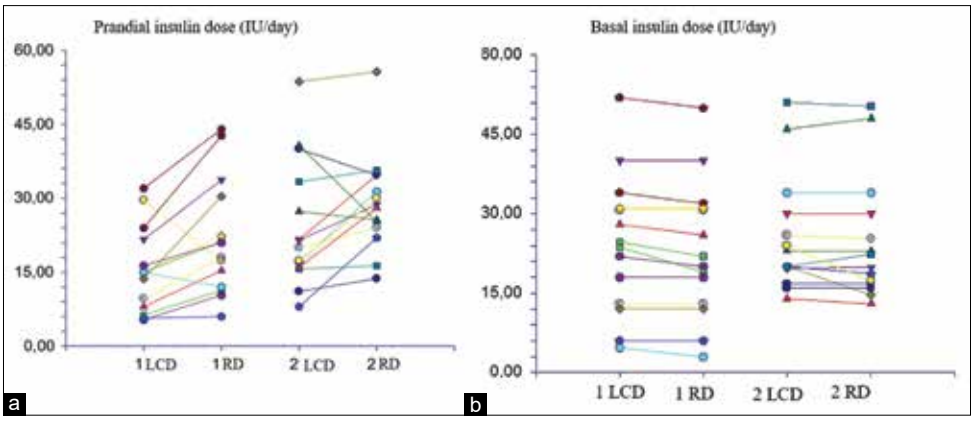

Figure 2: Insulin dose of subjects according to study groups during two diet periods 1LCD and 2LCD: subjects who started with low-carb diet and changed to regular diet after washout period (1) and vice versa (2) during low-carb diet 1RD and 2RD: same groups, respectively, during regular diet (a) prandial insulin dose (IU/day) and (b) basal insulin dose (IU/day)

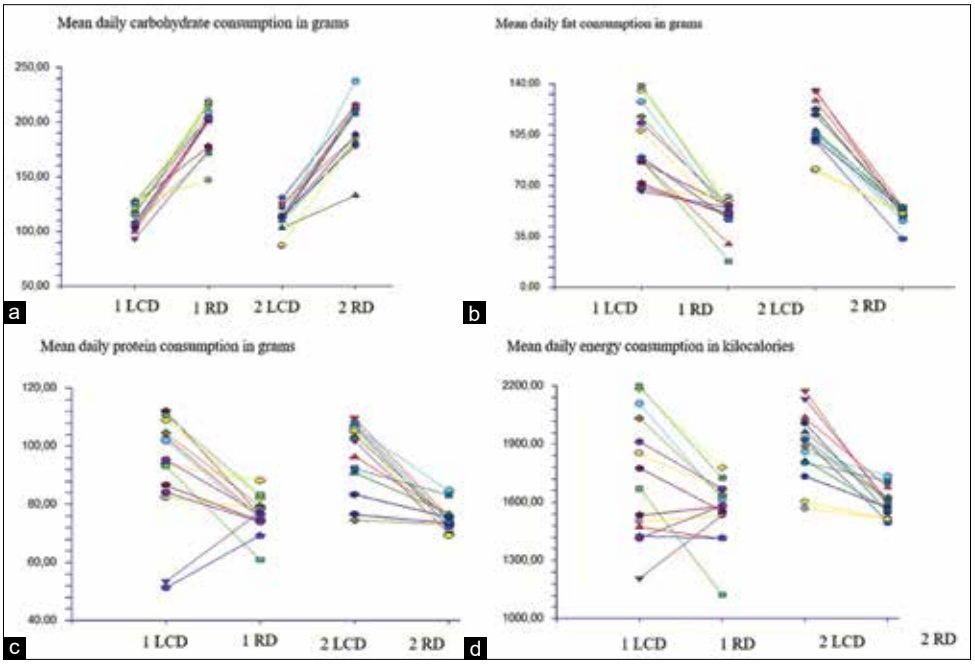

Figure 3: Diet composition of the subjects during the study 1LCD and 2LCD: subjects who started with low-carb diet and changed to regular diet after washout period (1) and vice versa (2) during low-carb diet 1RD and 2RD: same groups, respectively, during regular diet (a) mean daily carbohydrate consumption in grams, (b) mean daily fat consumption in grams, (c) mean daily protein consumption in grams, and (d) mean daily energy consumption in kilocalories

intake is suggested.[11] On the other hand, attempts of lowering the carbohydrate ratio in the diet are observed historically in noninsulin era of diabetes treatment, in early examples of some weight-loss programs (Atkins diet), in more actual weight-loss regimens in adults, children, athletes, in type 2 diabetic adults (supported by The American Diabetes Association (ADA) as well), and in large cohorts of general population with respect to cardiovascular disease.[3,4,12,13] It is noteworthy that newer recommendations for the nutrition management in pediatric diabetes are allowing to decrease the carbohydrate consumption till 40% of total energy.[14]

There are very few publications about LCD in type 1 diabetes and in pediatric diabetes.[15] Studies looking at glycemic outcomes from low-carbohydrate diets have largely been cross-sectional, without validated dietary data and with a lack of control groups. The participants are highly motivated self-selected individuals who follow intensive insulin management practices, including frequent blood glucose monitoring, and additional insulin corrections with tight glycemic targets. These confounders limit the ability to determine the extent of the impact of dietary carbohydrate restriction on glycemic outcomes.[16]

One of them is a case series from Australia which claims harmful effects like growth disturbances, hypocalcemia, hypercholesterolemia, and psychological problems.[7] But when one looks to the cases presented in the study closely,

they seem to have been affected not only by the diet regimen, some behavioral and psychosocial issues related to their family environment could have any impact as well. In fact, pushing smaller children to any kind of strict diet might be harmful even in much better familial conditions. The other one is a retrospective observational study in a quite large number of type 1 diabetes children, which is reporting a favorable metabolic control with LCD, but this study is again an observational one.[8] In both papers, LCD was used with parental initiative. We conducted in the past a short-term small cross-over study in 10 late adolescent type 1 diabetes girls to compare the effects of LCD on sensor-measured glycemia which revealed lower insulin requirement and mean glycemia and glycemic excursions during LCD.[17]

In the present study, we aimed to extend the group and observe the subjects more closely in a hospital setting. To overcome the disadvantage of studying a quite small group, we choose to homogenize the study subjects by means of gender and growth–puberty stage. Thus, we studied solely girls in late puberty. Since girls experience growth spurt at Tanner stage 2 unlike boys experiencing the same at stage 3, Tanner stage 3 was defined as a later stage of puberty. If subjects from both sexes and from a wider age spectrum were selected, subgroup comparisons would poorly reflect statistical differences. The additional comforts of doing so were the ease to convince the subjects to any diet, to create peer relations facilitating adherence, and to exclude potential effects on future growth if subjects would choose to continue with LCD in their daily life. Childhood is a very dynamic and variable status by means of growth patterns and every period of childhood must be studied separately about interventions with potential effect on growth. In the present short-term study, growth could not be analyzed, but future studies relying on our short-term findings should consider this detail.

In this study, we changed the meal planning from prefixed to more flexible soon after the start. The reason is that we confronted difficulties with compliance. For incompliance, the denial of protein-dense foods in some subjects, the difficulties to eat all the foods served, and disliking the hospital served foods were the main reasons. In the second day of the first week, we decided this change and we asked the subjects to generally comply with suggested corresponding carbohydrate ratio and to approximate upper and lower limits of protein and fat consumption. Additionally, we supported them with taste enhancers. We were fortunate at the end that we reached our general macronutrient composition targets, that is, significantly lower carbohydrates and higher fats and proteins during LCD. Although it was not a target of our study, we observed significantly higher energy intake during LCD. In fact, this is an expected outcome and an advantage of LCD. In studies among obese subjects, LCD causes weight loss despite higher energy intake which is attributed to the suppression of the insulin secretion.[12] On the other hand, subjects reported satiety, especially during LCD, although this was not investigated.

One can criticize our study design since we recruited some subjects (not all) during school period. This was our difficulty as well when convincing the subjects to attend to the study. But this was a 10-week study; we knew our patient's metabolic and psychosocial backgrounds very well, and subjects and study team were very familiar with each other from camps and frequent social activities, so they could arrange easily their school weeks and a considerable number of them needed, in fact, metabolic arrangement, diet, and carbohydrate-counting education and motivation. The presented patient characteristics reveal their suboptimal metabolic control. The circumstances we created satisfied these needs as well so that we could call this as a "win-win" situation. Among the subjects, group 2 had slightly higher insulin resistance parameters. Since this is a cross-over study and comparisons were made between intervention periods, not the "groups," we do not expect this to affect the outcomes.

Prandial insulin dose was lower and glycemic parameters better during LCD. Wang *et al*.[18] showed recently in a mice study that Low Carbohydrate (LC)-high protein and Omega-3 diet inhibit gluconeogenesis which in turn prevents glycemic excursions. That basal insulin dose was higher during LCD could be attributed to the consumption of foods which increase blood sugar in postprandial 3–5 h.[19] This effect could be overcome with insulin pumps. We allowed and moreover asked them to eat snacks for the sake of homogeneity. Criticizing retrospectively, using short-acting insulins, especially during LCD, they did not need these snacks. But snacks helped to compliance. It is debated sometimes that LCD arises hypoglycemia risk. This is not true since lower prandial dose means lower risk of unwanted insulin effect when insulin and food absorption do not match very well.[20] Although carbohydrate intake was lower in the LCD group than in the RD group, the total macronutrient and calorie intake was higher in the LCD group. Therefore, we may not have been able to differ in postprandial glucose values at all meals. Protein and fat counting in addition to carbohydrate counting might help to obtain better postprandial glycemic results. Our study was too short to adjust insulins for enormously decreasing carbs as well as protein and fat counting and subjects were not pump users. With a gradual decrease of carbs and a well-macronutrient counting education, one could expect even better results.

Hence, low-carbohydrate diets require attention to vitamin and energy intake to avoid micronutrient deficiencies and growth issues. Adherence to restricted diets is challenging and can have an impact on social normalcy. In individuals with type 1 diabetes, adverse health risks such as diabetic ketoacidosis, hypoglycemia, dyslipidemia, and glycogen depletion remain clinical concerns.[16] Neither hypoglycemia nor ketosis was observed in our study.

Another challenge of our study was insulin adjustment. Since the time was too short to define appropriate dosages, we observed lots of excursions during both periods. Having overcome this problem, we could achieve more clear-cut differences

especially regarding excursions which we hypothesized at the start. But long-term studies and observations about younger age groups might be useful.

Conclusion

Low carbohydrate (24% of daily energy in our series) diet is tolerable in adolescent diabetic girls. There is no risk of ketosis or hypoglycemia in short term. A similar or better glycemic control despite smaller insulin dose, increased energy, and satiety could be achieved when decreasing carbohydrates. The effect on body weight was not shown in our study but elsewhere might be an advantage as well in adolescent girls who aim to lose weight. Long-term effects on lipids and other cardiovascular parameters in type 1 diabetes remain to be elucidated. The suggested harmful effects on growing children are rather noteworthy regarding psychological issues unless their social environment has switched to lower carbohydrate consumption.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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