The Carbohydrate Counting in Adolescents With Type 1 Diabetes (CCAT) Study

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Abstract

This article reports pilot study results evaluating the accuracy of carbohydrate counting among adolescents with type 1 diabetes. This cross-sectional observational study included 48 adolescents ages 12–18 years (mean 15.2 ± 1.8 years) with type 1 diabetes of > 1 year in duration (mean A1C 8.0 ± 1.0%) who used insulin:carbohydrate (I:C) ratios for at least one meal per day.

The adolescents were asked to assess the amount of carbohydrate in 32 foods commonly consumed by youths. Foods were presented either as food models or as actual food, with some items presented as standard serving sizes and some self-served by study participants.

T-tests were used to assess the significance of over- or underestimation of carbohydrate content. For each meal, accuracy was categorized as accurate (within 10 grams), overestimated (by > 10 grams), or underestimated (by > 10 grams) based on the commonly used I:C ratio of 1 unit of insulin per 10 grams of carbohydrate.

Only 23% of adolescents estimated daily carbohydrate within 10 grams of the true amount despite selection of common meals. For dinner meals, individuals with accurate estimation of carbohydrate grams had the lowest A1C values (7.69 ± 0.82%, $P = 0.04$).

The pilot study provides preliminary evidence that adolescents with type 1 diabetes do not accurately count carbohydrates. Further data are needed on carbohydrate counting accuracy and other factors that affect glycemic control.

The incidence of type 1 diabetes is increasing worldwide,[1] and the prevalence of type 1 diabetes in youth in the United States is 1.54 per 1,000.[2] To prevent the complications of type 1 diabetes, the primary diabetes management goal is to maintain blood glucose levels as close to normal as is safely possible. The American Diabetes Association (ADA) has established targets for glycemic control as measured by A1C values. Unfortunately, many patients have A1C values that exceed the ADA goal.[3] Elevated postprandial glucose levels may contribute to the failure to attain optimal glycemic control.[4] The total amount of carbohydrate consumed strongly predicts glycemic response; therefore, monitoring total carbohydrates by either an exchange system or carbohydrate counting is crucial to achieving glycemic control.[5,6]

No data exist on accuracy of carbohydrate counting in youth with type 1 diabetes, yet this task is an integral part of their daily self-care. Both continuous subcutaneous insulin infusion (CSII) and multiple daily injection (MDI) regimens are designed to lower A1C values and reduce glycemic variability.[6–9] Both require patient (or parent) assessment of carbohydrate intake to determine proper prandial insulin dosing.[10,11] Thus, accurate estimation of total carbohydrates to be consumed is crucial to achieving adequate glycemic control.[5,6]

Carbohydrate counting in the treatment of youth with type 1 diabetes is not a new approach. However, the meal planning based

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on carbohydrate counting has become more common since the introduction of rapid-acting insulin analogs in CSII and MDI regimens. The 2007 ADA nutrition recommendations state that individuals practicing intensive insulin therapy should adjust their premeal doses based on the carbohydrate content of their meals.[10] Surprisingly, there have been no randomized controlled studies specifically proving the efficacy of carbohydrate counting in youth with diabetes,[11] and no standardized approach to assessing the accuracy of carbohydrate counting is available.

The overall goal of this project is to advance methods, through assessing the accuracy of carbohydrate counting, for optimizing glycemic control in adolescents with type 1 diabetes. Ultimately, this program of translational research seeks to improve the effectiveness of nutrition education related to carbohydrate counting and to increase the accuracy of mealtime rapid-acting insulin dosing among adolescents with type 1 diabetes. Herein, we report development of new measures and methods from a pilot study aimed to evaluate the accuracy and correlates of accuracy of carbohydrate counting among adolescents with type 1 diabetes.

Research Design and Methods

The study included adolescents aged 12–18 years with type 1 diabetes (as defined by ADA criteria)[12] for > 1 year who received care from the Barbara Davis Center for Childhood Diabetes in Denver, Colo., and were using insulin:carbohydrate (I:C) ratios for at least one meal per day. The center treated > 1,400 patients between the ages of 12 and 18 years in 2005. Patients coming in for routine follow-up exams were contacted about possibly participating in the study. Patients with celiac disease, type 1 diabetes of < 1 year's duration, an A1C > 12%, or who were non–English speaking were excluded from the study. Fifty individuals provided consent, although one declined to complete the study and one was later deemed ineligible. Therefore, data were analyzed from 48 participants.

Participants assessed the carbohydrate content for 32 foods presented as typical breakfasts, lunches, dinners, and snacks (e.g., banana [snack] or cereal with milk [breakfast]) commonly consumed by youths. Registered dietitians (RDs) selected the foods to be included after reviewing diet records and dietary data collected from youths with diabetes.[13]

Foods were presented either as food models or as actual food, with some items presented as standard serving sizes and some self-served by the study participants. Packaged real food items were presented to participants with their Nutrition Facts labels, and participants were allowed to use these food labels if they wished. Participants recorded their estimate of portion size, carbohydrate content, and frequency of consumption. Study staff recorded the use of nutrition labels by participants during the study visit (for foods that were presented with a nutrition label). For self-served foods, the actual weight of the food served was recorded out of sight of the participants. The amount of carbohydrate in each food was determined by either the nutrition label for packaged foods, the Nasco Food Replica Nutrition Guide (based on the U.S. Department of Agriculture's *A Standard Reference for Nutrient Composition* for food models, or the Nutrient Data System for Research (Version 2007) software licensed from the Nutrition Coordinating Center at the University of Minnesota for foods that were self-served by study participants.

An interviewer-administered questionnaire assessed participants' carbohydrate counting education, family/friend support for carbohydrate counting, and patterns of carbohydrate counting (i.e., at which meals and snacks they count carbohydrates and how often). A1C levels were measured as part of patients' clinical visits. All participants provided informed consent and/or assent, and the study was approved by the local institutional review board.

Statistical Methods

From the 32 commonly consumed foods, typical breakfasts, lunches, dinners, and snacks were constructed along with typical whole-day menus (three meals and a snack). Accuracy of carbohydrate counting was determined as the difference between actual and participant-estimated carbohydrate content (in grams) for each food, meal, and daily menu. Researchers determined the number of participants who estimated carbohydrates accurately within 5 grams for individual food/food combinations or within 10 grams for meals or snacks based on clinical application of a common I:C ratio for adolescents of 1 unit of insulin for each 10 grams carbohydrate consumed.

T-tests were used to assess the significance of over- or underestimation of carbohydrate content. To describe accuracy for whole days (three meals and a snack), levels of accuracy were considered as accuracy within 10 g/day, within 20 g/day, and within 30 g/day. Comparisons of mean A1C levels across categories of accuracy were made by analysis of variance.

All analyses were performed using SAS 9.0 software (SAS Institute Inc., Cary, N.C.). Despite some concern for multiple comparisons, because this was a feasibility pilot study and the project was not formally powered to test hypotheses related to accuracy of carbohydrate counting, investigators simply considered a P value of < 0.05 as statistically significant.

Results

As shown in Table 1, participants were categorized by their carbohydrate counting accuracy level as accurate (within 10 g of true amount), overestimated (by > 10 g of true amount), or underestimated (by > 10 g of true amount) based on the commonly used I:C ratio of 1:10. Participants (mean age 15.2 ± 1.8 years, 52% female, 85% non-Hispanic white, 55% using CSII) had an average A1C of 8.0 ± 1.0% (range of 6.2–10.8%) and an average diabetes duration of 67 ± 45 months (range 13–183 months).

Seventy-four percent of participants received carbohydrate counting instruction from an RD, although

Table 1. Demographics and Education

	Accurate (within ± 10 g)	Overestimated (by > 10 g)	Underestimated (by > 10 g)	*P* value*
Age (years)	15.7 ± 1.5	15.0 ± 1.9	15.2 ± 1.8	0.65
Sex (*n* [%])				
Female	7 (64)	11 (50)	7 (47)	0.76
Male	4 (36)	11 (50)	8 (53)	
BMI *z*-score	0.50 ± 0.64	0.64 ± 0.68	0.78 ± 1.06	0.69
Insulin regimen (*n* [%])				
MDI	5 (45)	8 (36)	8 (57)	0.52
CSII	6 (55)	14 (64)	6 (43)	
Carbohydrate counting help (*n* [%])				
Never or rarely	5 (45)	11 (50)	5 (33)	0.65
Sometimes, usually, always	6 (55)	11 (50)	10 (67)	
Years carbohydrate counting (*n* [%])				
1–2.9 years	4 (36)	12 (55)	9 (60)	0.53
3+ years	7 (64)	10 (45)	6 (40)	
Carbohydrate counting education from dietitian (*n* [%])				
No	3 (27)	4 (8)	5 (36)	0.52
Yes	8 (73)	18 (82)	9 (64)	
Most recent carbohydrate counting education from dietitian (*n* [%])				
Last year	1 [14]	5 (28)	3 (43)	0.51
Over a year ago	6 (86)	13 (72)	4 (57)	
Most likely to carbohydrate count/meal (*n* [%])				
All meals and snacks	8 (73)	9 (41)	7 (47)	0.25
Some meals	3 (27)	13 (59)	8 (80)	
Least likely to carbohydrate count/meal (*n* [%])				
All meals and snacks	5 (45)	5 (23)	3 (20)	0.29
Some meals	6 (55)	17 (77)	12 (80)	

Table 2. Mean Difference Between Carbohydrate Content Estimated by Patient and Actual Content (grams)

	n	Mean	SD	Lower 95% CI	Upper 95% CI	*P* value†
Cereal* (L)	48	−9.1	17.7	−14.3	−4.0	0.0008
Milk* (L)	48	4.5	5.3	3.0	6.1	< 0.0001
Eggos	48	3.9	8.9	1.4	6.5	0.0035
Syrup* (L)	48	8.6	10.3	5.7	11.6	< 0.0001
Scrambled eggs	48	1.4	3.7	0.3	2.5	0.0110
Hash browns	48	6.3	7.2	4.2	8.4	< 0.0001
Bacon	48	1.9	4.8	0.5	3.3	0.0087
Pizza, cheese	48	−4.3	12.2	−7.8	−0.7	0.0196
Pizza, pepperoni	47	−3.2	13.0	−7.0	0.6	0.0942
Bread	48	−1.9	7.2	−4.0	0.2	0.0695
Peanut butter	48	0.4	4.8	−1.0	1.8	0.5713
Jelly	47	0.1	6.9	−1.9	2.1	0.9329
Burger	48	3.0	6.5	1.1	4.8	0.0027
Bun	48	3.7	7.2	1.6	5.8	0.0008
Chicken	48	3.0	6.3	1.2	4.8	0.0017
Rice	48	6.5	8.9	3.9	9.0	< 0.0001
Corn	48	1.3	7.6	−0.9	3.5	0.2489
Spaghetti*	47	13.0	16.2	8.2	17.7	< 0.0001
Sauce*	47	2.4	9.2	−0.3	5.1	0.0767
Broccoli*	47	2.2	5.6	0.6	3.9	0.0101
Chicken nuggets (L)	48	3.9	7.8	1.6	6.2	0.0012
Fries (L)	48	−7.3	11.5	−10.6	−4.0	< 0.0001
Barbecue sauce	48	−3.2	6.9	−5.2	−1.2	0.0021
Macaroni and cheese	48	−4.3	13.2	−8.2	−0.5	0.0277
Carrots	48	2.3	5.8	0.6	4.0	0.0081
Snack milk* (L)	48	4.4	5.8	2.7	6.1	< 0.0001
Soda	48	−19.7	23.2	−26.5	−13.0	< 0.0001
Apple juice (L)	47	−7.0	14.2	−11.1	−2.8	0.0015
Apple	47	−1.6	8.1	−4.0	0.8	0.1743
Banana	47	−4.8	9.2	−7.5	−2.0	0.0010
Chips* (L)	47	6.6	7.8	4.3	8.9	<0.0001
Cookies* (L)	47	−1.1	5.6	−2.7	0.6	0.1917

▇ Overestimation, ▇ Underestimation, ☐ Accurate estimation
*Self–served foods
(L), Nutrition Label present in study visit
†Two–sided *T*–test H0 = 0

72% of these instructions were > 1 year before participation in this study. The remainder of participants received carbohydrate counting education from their physician, nurse, books/printed materials, and the Internet (Table 1).

Participants were also asked at which meals they were most or least likely to count carbohydrates, but no statistically significant pattern was found (Table 1). Additionally, participants were asked how often they receive help with carbohydrate counting, but no statistically significant differences were found among the three carbohydrate counting categories. In other words, the participants who received the most help with carbohydrate counting did not do significantly worse in carbohydrate counting by themselves than those who always counted carbohydrate for themselves.

Statistically significant overestimation of carbohydrate content was observed for 15 of 32 foods in the quiz (Table 2). Syrup, hash browns, rice, spaghetti, and chips were overestimated by more than 5 g/serving. Statistically significant underestimation of carbohydrate content was observed for 8 out of 32 foods in the quiz, with cereal, French fries, and soda underestimated by more than 5 g. Overall, carbohydrate accuracy for an average breakfast was +7.2 ± 15.1 g; lunch was −7.9 ± 16.7 g; dinner was +3.8 ± 17.3 g, and accuracy for average daily snacks was +0.8 ± 13.6 g.

Table 3. Carbohydrate Counting Accuracy* Distribution by Average Meals

		Categorized by Carbohydrate Accuracy			
		Accurate	Overestimated	Underestimated	*P* value
Average day (± 10 g)	*n* (%)	11 (23)	22 (46)	15 (31)	
	A1C	8.1 ± 1.2%	8.3 ± 1.0%	7.7 ± 0.9%	0.21
Average day (± 20 g)	*n* (%)	15 (31)	20 (42)	13 (27)	
	A1C	8.1 ± 1.2%	8.2 ± 1.0%	7.8 ± 0.9%	0.52
Average day (± 30 g)	*n* (%)	25 (52)	13 (27)	10 (21)	
	A1C	8.0 ± 1.1%	8.3 ± 1.0%	7.9 ± 1.0%	0.60
Average breakfast (± 10 g)	*n* (%)	22 (46)	20 (42)	6 (13)	
	A1C	7.8 ± 1.1%	8.3 ± 0.9%	8.0 ± 1.2%	0.35
Average lunch (± 10 g)	*n* (%)	18 (38)	6 (13)	24 (50)	
	A1C	8.2 ± 1.0%	8.1 ± 1.0%	7.9 ± 1.1%	0.63
Average snacks (± 10 g)	*n* (%)	30 (64)	9 (19)	8 (17)	
	A1C	7.8 ± 1.0%	8.7 ± 0.9%	8.2 ± 1.1%	0.08
Average dinner (± 10 g)	*n* (%)	21 (44)	18 (38)	9 (19)	
	A1C	7.7 ± 0.8%	8.5 ± 1.2%	7.9 ± 1.0%	0.04

**Accuracy for meals/snacks was defined as within 10 g/serving; accuracy for the average of three daily menus was evaluated as within 10 g/day, within 20 g/day, and within 30 g/day.*

As shown in Table 3, only 11 of 48 (23%) adolescents estimated daily carbohydrates within 10 g of the true amount despite selection of common meals, and only 15 (31%) estimated accurately within 20 g/day. For dinner meals, individuals with accurate estimation of carbohydrate grams had the lowest A1C values (7.7 ± 0.8%) with A1C levels of 8.5 ± 1.2% and 7.9 ± 1.0% for those in the overestimated and underestimated groups, respectively ($P = 0.04$ comparing across three categories).

Discussion

The findings in this pilot study indicate that adolescents with type 1 diabetes do not accurately count carbohydrates and commonly either over- or underestimate carbohydrate grams in a given meal. Adolescents with accurate (within 10 g) carbohydrate assessment had the lowest A1C values, and this was statistically significant for the dinner meals. Adolescents who overestimated the carbohydrate grams at dinnertime had the highest A1C values.

Although this initially seems counterintuitive, one might speculate that routine excess insulin bolusing because of overestimation of anticipated carbohydrate ingestion may lead to hypoglycemia, with subsequent overtreatment of low blood glucose leading to chronically higher glucose levels. Or, from a clinical perspective, if an adolescent underestimates the carbohydrate content in a given meal by 10 g, and he or she is using an I:C of 1:5, the prandial insulin dose administered would be 2 units less than actually needed, likely resulting in postprandial hyperglycemia.

From an efficacy perspective, the Diabetes Control and Complications Trial results demonstrated that adjusting insulin for meal size and content using meal-planning strategies (including carbohydrate counting, the exchange system, weighing and measuring food, and estimating portion sizes) in the intensively managed group was associated with improved glycemic control.[8] The Dose Adjustment for Normal Eating study group in the United Kingdom found that adult patients with type 1 diabetes who were taught how to use flexible intensive insulin regimens with I:C ratios improved their A1C values by 1% after 6 months and reported improved quality of life.[14] Adjusting insulin doses to match carbohydrate intake can enhance adolescents' independence and feelings of normalcy and increase communication and trust with their health care team.[15]

One of the only studies assessing carbohydrate counting accuracy in type 1 diabetic patients was reported by Rabasa-Lhoret et al.[6] and only included nine adult patients. The investigators presented correlation data between patient and nutritional software–assisted evaluation of carbohydrate content of meals and found 85.2% of participants' carbohydrate evaluation was within 15% of the computer-assisted carbohydrate assessment.[6]

Despite some concern for multiple comparisons, because this was a feasibility pilot study and the project was not formally powered to test hypotheses related to accuracy of carbohydrate counting, we considered a P value of < 0.05 as statistically significant. Also, the use of a combination of foods with real foods in standard serving sizes, real foods as self-serve, and food models may have introduced some bias into the study. Additionally, food models are in a standard serving size that might be easier for participants to estimate; however, there was no difference found in accuracy between food models, real foods in standard serving sizes, and self-served foods.

No data are available assessing the accuracy of carbohydrate counting in adolescents, although this task is part of their daily diabetes self-care. The pilot study reported here includes adolescents specifically and suggests that in a larger sample of patients with type 1 diabetes, carbohydrate counting is less accurate when compared to true carbohydrate content of food.

Summary

From a practical perspective, preliminary findings from this pilot project suggest that adolescents seen for diabetes care in a specialty clinic do not count carbohydrates of commonly consumed foods with acceptable accuracy. Given the need for accurate insulin bolusing to achieve optimal glycemic control, this represents an understudied aspect of diabetes care with the potential to improve patient outcomes.

Future studies will need to address many limitations of this initial pilot project; include a larger sample size; collect data on participants' actual insulin bolusing, their postprandial glucose levels, and their daily glucose variability; and include consideration of other factors important to glucose control, such as physical activity and dietary factors other than carbohydrate intake. This study was cross-sectional and only looked at a one-time measurement of carbohydrate counting accuracy and A1C, both of which can change over time due to multiple factors. Better understanding of these relationships is needed to improve clinical care of youths with type 1 diabetes. This work will help RDs, diabetes educators, and patients self-managing their diabetes using either MDI or CSII regimens by providing data to make more informed bolusing decisions that optimally incorporate both diet and physical activity behaviors.

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References

[1]Onkamo P, Vaananen S, Karvonen M, Tuomilehto J: Worldwide increase in incidence of type I diabetes: the analysis of the data on published incidence trends. *Diabetologia* 42:1395–1403, 1999

[2]Liese AD, D'Agostino RB Jr, Hamman RF, Kilgo PD, Lawrence JM, Liu LL, Loots B, Linder B, Marcovina S, Rodriguez B, Standiford D, Williams DE: The burden of diabetes mellitus among US youth: prevalence estimates from the SEARCH for Diabetes in Youth Study. *Pediatrics* 118:1510–1518, 2006

[3]Danne T, Mortensen HB, Hougaard P, Lynggaard H, Aanstoot HJ, Chiarelli F, Daneman D, Dorchy H, Garandeau P, Greene SA, Hoey H, Holl RW, Kaprio EA, Kocova M, Martul P, Matsuura N, Robertson KJ, Schoenle EJ, Sovik O, Swift PG, Tsou RM, Vanelli M, Aman J: Persistent differences

among centers over 3 years in glycemic control and hypoglycemia in a study of 3,805 children and adolescents with type 1 diabetes from the Hvidore Study Group. *Diabetes Care* 24:1342–1347, 2001

[4]American Diabetes Association: Postprandial blood glucose [Position Statement]. *Diabetes Care* 24:775–778, 2001

[5]Sheard NF, Clark NG, Brand-Miller JC, Franz MJ, Pi-Sunyer FX, Mayer-Davis E, Kulkarni K, Geil P: Dietary carbohydrate (amount and type) in the prevention and management of diabetes: a statement by the American Diabetes Association. *Diabetes Care* 27:2266–2271, 2004

[6]Rabasa-Lhoret R, Garon J, Langelier H, Poisson D, Chiasson JL: Effects of meal carbohydrate content on insulin requirements in type 1 diabetic patients treated intensively with the basal-bolus (ultralente-regular) insulin regimen. *Diabetes Care* 22:667–673, 1999

[7]Gillespie SJ, Kulkarni KD, Daly AE: Using carbohydrate counting in diabetes clinical practice. *J Am Diet Assoc* 98:897–905, 1998

[8]Delahanty LM, Halford BN: The role of diet behaviors in achieving improved glycemic control in intensively treated patients in the Diabetes Control and Complications Trial. *Diabetes Care* 16:1453–1458, 1993

[9]Bantle JP, Wylie-Rosett J, Albright AL, Apovian CM, Clark NG, Franz MJ, Hoogwerf BJ, Lichtenstein AH, Mayer-Davis E, Mooradian AD, Wheeler ML: Nutrition recommendations and interventions for diabetes—2006 [Position Statement]. *Diabetes Care* 29:2140–2157, 2006

[10]American Diabetes Association: Nutrition recommendations and interventions for diabetes [Position Statement]. *Diabetes Care* 30 (Suppl. 1):S48–S65, 2007

[11]Kawamura T: The importance of carbohydrate counting in the treatment of children with diabetes. *Pediatr Diabetes* 8 (Suppl. 6):57–62, 2007

[12]American Diabetes Association: Clinical practice recommendations 2002. *Diabetes Care* 25 (Suppl. 1):S1–S147, 2002

[13]Mayer-Davis EJ, Nichols M, Liese AD, Bell RA, Dabelea DM, Johansen JM, Pihoker C, Rodriguez BL, Thomas J, Williams D: Dietary intake among youth with diabetes: the SEARCH for Diabetes in Youth Study. *J Am Diet Assoc* 106:689–697, 2006

[14]DAFNE Study Group: Training in flexible, intensive insulin management to enable dietary freedom in people with type 1 diabetes: dose adjustment for normal eating (DAFNE) randomised controlled trial. *BMJ* 325:746, 2002

[15]Franz MJ, Horton ES Sr, Bantle JP, Beebe CA, Brunzell JD, Coulston AM, Henry RR, Hoogwerf BJ, Stacpoole PW: Nutrition principles for the management of diabetes and related complications [Technical Review]. *Diabetes Care* 17:490–518, 1994

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