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Accurate Carbohydrate Counting Is an Important Determinant of Postprandial Glycemia in Children and Adolescents With Type 1 Diabetes on Insulin Pump Therapy

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Abstract

Background: Carbohydrate (CHO) counting is a key nutritional intervention utilized in the management of diabetes to optimize postprandial glycemia. The aim of the study was to examine the impact of accuracy of CHO counting on the postprandial glucose in children and adolescents with type 1 diabetes on insulin pump therapy.

Methods: Children/adolescents with type 1 diabetes who were on insulin pump therapy for a minimum of 6 months are enrolled in the study. Patients were instructed to record details of meals consumed, estimated CHO count per meal, and 2-hour postprandial glucose readings over 3-5 days. Meals' CHO contents were recounted by an experienced clinical dietician, and those within 20% of the dietician's counting were considered accurate.

Results: A total of 30 patients (21 females) were enrolled. Age range (median) was 8-18 (SD 13) years. Data of 247 meals were analyzed. A total of 165 (67%) meals' CHO contents were accurately counted. Of those, 90 meals (55%) had in-target postprandial glucose ($P < .000$). There was an inverse relationship between inaccurate CHO estimates and postprandial glucose. Of the 63 underestimated meals, 55 had above-target glucose, while 12 of the 19 overestimated meals were followed by low glucose. There was no association between accuracy and meal size (Spearman's rho = .019).

Conclusion: Accuracy of CHO counting is an important determining factor of postprandial glycemia. However, other factors should be considered when advising on prandial insulin calculation. Underestimation and overestimation of CHO result in postprandial hyperglycemia and hypoglycemia, respectively. Accuracy does not correlate with meal size.

Keywords
carbohydrate, counting, diabetes, insulin pump

Novelty Statement

- We examined the impact of accuracy of CHO counting on postprandial glycemia in children on insulin pump therapy. To the best of our knowledge, this is the first report comparing data from our region within the international literature.
- The study confirmed the importance of CHO counting in normalizing the postprandial glucose.
- Our study showed a close association between underestimation and overestimation of the CHO load with postprandial hyperglycemia and hypoglycemia respectively.
- The study showed no association between accuracy of CHO counting and meal size.
- Beside accuracy of CHO counting, other factors play a role on the postprandial glycemia.

Introduction

Medical nutrition therapy has been identified as one of the key aspects in diabetes care.[1] Carbohydrate (CHO) quantification is a key nutritional intervention that is utilized in the management of children and adolescents with type 1 diabetes to optimize postprandial glycemic control. When included in a structured diabetes education program, CHO counting increases the

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flexibility in consumption of food type and quantity and results in improvement in glycemic control.[2] Comprehensive team-based diabetes education with targeted nutrition interventions is necessary for optimal diabetes outcomes.[3].

The principles of CHO counting has been in practice for over a century. As early as the days of discovering insulin, CHO counting was used in meal planning for individuals with diabetes.[4] The Diabetes Control and Complications Trial (DCCT) has renewed global interest in CHO counting after using it as 1 of 4 meal planning approaches in the DCCT. In the trial, CHO counting was found to be effective in meeting outcome goals and allowed flexibility in food choices.[5]

Medical nutrition therapy and in particular CHO counting has a major impact on hemoglobin A1c levels.[6] Optimizing postprandial glycemia is an important aim in the prevention of adverse outcomes for individuals with type 1 diabetes. Evidence suggests that postprandial hyperglycemic spikes are more strongly associated with carotid intima media thickness than fasting blood glucose or HbA1c.[7] While this evidence is stronger in type 2 diabetes, a similar effect is seen in people with type 1 diabetes.[8]

CHO counting is a widely used to quantify prandial insulin requirement. Theoretically, precise CHO quantification should have a direct effect on the postprandial blood glucose. Smart et al showed that 10-g variations in CHO quantity resulted in no differences in blood glucose or hypoglycemic episodes.[9] However, a 20-g difference (above or below) in a meal of 60 g resulted in hypo- and hyperglycemia, respectively.[10]

It is known that CHO has the most significant impact on raising postprandial blood glucose levels.[11] Accordingly, it is persuadable that careful counting of CHO will lead to the correct calculation of the required insulin dose, which in turn leads to normalizing postprandial glycemia.

Aim

The aim of the study is to examine the impact of accuracy of CHO counting on the postprandial glucose control in children and adolescents with type 1 diabetes using insulin pump therapy. We hypothesize that the more accurate the CHO counting, the closer the postprandial reading will be to the target glucose level.

Primary End Point

The primary end point is the correlation between accuracy of CHO counting and postprandial blood glucose.

Secondary End Points

The secondary end points are (1) the effect of underestimation/overestimation of CHO counting on postprandial glucose level and (2) the relationship between error margin in CHO counting and meal size.

Patients and Methods

Children/adolescents with type 1 diabetes who are on insulin pump therapy for a minimum of 6 months were approached to participate in the study. The study was explained verbally to patients, and they were given an information sheet about the study. Patients who agreed to participate were asked to sign a consent form.

The study method was in accordance with the Helsinki Declaration of 1975, as revised in 1983 and was approved by the Research & Ethics committee at Mafraq hospital.

Patients were asked to fill in a CHO intake diary for 3-5 days. The clinical dietician of the study team provided patients with food diaries to fill in and return to clinic. Details of meals were recorded, and their CHO counting calculation was listed next to each meal consumed. Patients who were 12 years and younger were helped by parents in counting their CHO, which is their usual routine outside the study. Patients were asked to count CHO in any method of CHO quantifications they have been taught: grams, 10-g portions, or 15-g exchange. Descriptions can also be in standard quantities: cups, food label information.

Patient were instructed to check their blood glucose 2 hours after meals and record them in the diary provided. Patients were asked not to eat or drink any food within the 2 hours. If exercise was done within the 2 hours, patients were asked to record its duration and how strenuous it was in a note in the diary.

Postprandial glucose was assessed and marked either as in target, or above or below. The patient's individual target was chosen as per standard clinical practice guidelines.[12]

Patients were trained on insulin pump use, and pumps were programmed by entering the appropriate insulin/CHO ratio and correction factor in the standard way of pump use. Insulin dosing was obtained through the insulin pump bolus wizard. No specific extra training or programming was done for the purpose of the study.

Diaries were returned to clinic, and all entries of CHO counted were recounted by a single experienced clinical dietician (AH). Accuracy of patient counting was assessed. Meals counting within 20% of the dietician's counting were considered accurate.

Statistical Method

Associations between categorical variables, such as "accurate," "glycemia within target," "glycemia below target," and "glycemia above target," were analyzed using standard cross-tabulations, chi-square tests, tests for trend (linear-by-linear where appropriate), and odds ratios. As there were fewer patients than observations, marginal odds ratios (the odds ratios if each observation would come from a different patient) were also estimated using GEE (generalized estimating equations) logistic regression with exchangeable error structure. To explore whether (significant) associations were

attributable to between or within patient associations, average per patients score (marginal means) were correlated using nonparametric Spearman's rho and within-patient associations using the Mantel-Haenszel procedure or logistic regression adjusted for the categorical variable "patient."

All analyses were carried out using SPSS version 22. A significance level of .05 (2-tailed) was used throughout.

Results

A total of patients were enrolled (21 females). Age range (median) was 8-18 (SD 13) years. Duration of diabetes ranged between 1.5 and 12 years, with a median of 7 years. All patients were on insulin pump treatment. In all, 19 patients were on Medtronic Minimed pump and 11 on Accu-Chek Combo system. Duration of pump use ranged between 0.5 and 7 years, with a median of 2.25.

Summary of Meals Counted and Accuracy

There was a total of 247 meals with CHO counting and a 2-hour postprandial reading. Average number of meals studied per patient was 8. Meal CHO contents ranged between 10 and 170 grams, with a median of 50 grams. On assessing accuracy, 165 (67%) meals CHO were counted within 20% of the dietician's counting and were considered accurate.

The Relationship Between Counting Accuracy and Postprandial Glycemia

In all, 165 meals were accurately counted. Of those, 90 meals (55%) had an in target postprandial glucose, while of the 82 meals inaccurately counted, only 18 (22%) were followed by a postprandial glucose in target. Cross-tabulation showed an association between inaccurate counting and postprandial glucose level outside the target ($P < .001$, chi-square test). There was no difference if the level was above or below the target.

The odds ratio of the association between accuracy of counting and postprandial glucose in target was 7.7 (95% CI 3.8-15.7). GEE logistic regression, taking into account that multiple observations came from the same patient, yielded a very similar odds ratio of 7.4 (95% CI 2.9-19.9). Within meals counted by the same patient, there was no association between accuracy of counting and postprandial glucose.

The Mantel-Haenszel procedure, to estimate the odds ratio adjusted for patients (ie, the association within patients), yielded an odds ratio of 9.7 (95% CI 4.2-22.7), indicating that the association exists within patients. The Spearman correlation between the mean accuracy level of each patient (fraction accurate per patient) and the mean score for in-target postprandial glucose for each patient yielded a value of 0.26 ($P = .17$), suggesting that the overall association was mainly due to a within-patient, rather than between-patient, association.

Table 1. Frequency of CHO Counting Accuracy in Relation to Postprandial Blood Glucose.

Postprandial glucose	Accurate CHO counting (n meals)	Inaccurate CHO counting (n meals)
Total	165	82
In target, $P < .000$	90 (55%)	18 (22%)
Not in target	75 (45%)	64 (78%)
Above target	65 (39%)	55 (67%)
Below target	10 (6%)	9 (11%)

$P < .000$ indicates statistical significance.

The Association Between Underestimation/Overestimation of Meals Count and Postprandial Hypo/Hyperglycemia

Postprandial blood glucose was within target after 108 (44%) meals consumed and not in target in 139. After 19 meals (8%), blood glucose was below target, and after 120 (48%) it was above target. In all, 10 (6%) of the accurately counted meals had a postprandial below target, and in 65 (39%) the glucose reading was above target (Table 1).

The 82 meals inaccurately counted were recorded by 27 patients. Of the meals, 63 (77%) had an underestimation of CHO. Underestimation of meal size was seen in 25 patients' records at an average of 3 underestimated meals by patient. Conversely, 19 (23%) meals had overestimated CHO contents by 16 patients. Of the 63 underestimated meals, 55 (87%) showed higher postprandial glucose. In 7, glucose was in target and in 1 below target. Conversely, in the 19 overestimated meals, 12 (63%) were followed by a glucose under the target, 4 in target, and 3 above (Table 2). A linear-by-linear trend test between glycemia (below, within, above target) and overestimation/underestimation of meal count (among inaccurately estimated meals) was highly significant ($P < .001$). Similarly, a trend test of the association between glycemia and meal estimation (below, accurate, above) also gave a highly significant association ($P < .001$; Spearman's rho = –.49) indicating a strong (negative) linear relationship between the variables. This observation was confirmed by GEE logistic regression among observations with inaccurate meal count estimation and over-/underestimation as the dependent variable. To assess within-patient association, standard logistic regression was done with "patient" as a fixed categorical variable, which yielded a highly significant negative association and a "per step" odds ratio of nearly zero.

The Relationship Between Counting Accuracy and Meal Size

Meal CHO contents ranged between 10 and 170 grams. The mean (SD) of those accurately counted was 59.8 (32.6), and it was 53.5 (31.5) for the inaccurately counted ($P = .15$ by *t*-test)

Table 2. Distribution of the Inaccurate CHO Meals Based on Postprandial Glucose.

Postprandial glucose	Underestimated carbohydrate (n meals)	Overestimated carbohydrate (n meals)	Total
In target	7 (11%)	4 (21%)	11
Above target	55 (87.5%)	3 (16%)	58
Below target	1 (1.5%)	12 (63%)	13
Total	63	19	82

The Spearman's correlation coefficient between accuracy of counting (below, accurate, above) and meal size was only .019 ($P = .77$), again indicating a lack of association.

Discussion

CHO counting is a commonly used method for estimation of prandial insulin. It is a meal planning approach for patients with diabetes that focuses on CHO as the primary nutrient affecting postprandial glycemic response. Dietary education is an integral part of diabetes management. For patients to master CHO counting, repeated age-appropriate education is necessary to maintain accuracy in CHO.[13] The calculation of prandial insulin dose is a complex process in which many factors should be considered.[14] Studies suggest that CHO counting is difficult for both health professionals and children and adolescents with diabetes.[15] Similarly, Shapira et al reported the standard deviations of the estimated CHO contents were large and increased with increasing CHO loads.[16] However, in another study, it was shown that children with type 1 diabetes and their caregivers can estimate the CHO content of meals with reasonable accuracy. Of estimated CHO countings, 73% were within 10-20 grams of the accurate count with children using CHO counting for longer duration having higher margin of error.[13] In our group, 67% counted their meals accurately. Unlike Shapira et al, who showed that large meals tended to be underestimated and snacks overestimated,[16] we did not find a correlation between accuracy of counting CHO and the meal size. Underestimation of CHO content was commonly seen in our group. One contributing factor could be fear of hypoglycemia.

Various systems in food counting are utilized to educate patients using insulin pump therapy. Many methods of counting CHO have been used, and many are still commonly used in pediatric practice (exchange, portion/serving, grams, glycemic index, CHO/insulin ratio). Diabetes software is another method used. Błazik and Pańkowska demonstrated that Warsaw Pump Therapy School is safe and reduces postprandial glucose and glucose variability without increasing the risk of hypoglycemia.[17] Others devised equations for metabolism of CHO and for insulin response and used them as a model to estimate prandial insulin requirement. The authors claimed that this model is superior to CHO counting method for achieving diabetes control.[18]

Food labels have been an important source of dietary information. Using food label information is a way to practice CHO counting. While it is encouraged to follow label contents, it has been shown that variation between the label and actual CHO count can be up to 45%.[19]

In our center, the majority of the patients were trained to count CHO in grams and read food labels. Some used scales in assessing CHO contents.

Accepted methods of defining accuracy in CHO counting vary in different studies. In some, accuracy was considered with counting ranging from ±10 grams over the whole day of meals.[15] Alternatively, accuracy was defined by estimates within 20% of the actual CHO amount.[20] We have chosen to use the latter to define accuracy for our group.

Both the amount and type of CHO in a meal influence postprandial blood glucose levels. However, the amount rather than the glycemic index (GI) of the CHO in the food is most often the primary determinant of postprandial response.[11] Glycemic load indicated by the CHO amount has been shown to be a main indicator of the glucose response and insulin requirement induced by diet and is the most important determinant of postprandial glucose increase.[21] Slama et al reported that the total amount of insulin required to maintain glycemia is highly correlated with the quantity of the CHO consumed and not the type of CHO.[22] In agreement with the previous results, it was shown that insulin adjustment correlated with the CHO amount, not type, and the insulin adjustment was not affected by the GI, fiber, fat, or energy content of the meals.[23]

Evidence suggests that consuming low glycemic index rather than high GI foods reduces the postprandial excursions and improves glycemic control.[24] GI is not currently incorporated into the calculation of the mealtime bolus in pump therapy; however, the type of bolus is advised to vary based on GI. It was reported that the dual wave/combo bolus decreased the glucose excursion postprandially.[25] In our region, it is popular to consume large amounts of sweetened drinks and high-energy food.[26] However, we have not studied the GI content of the meals described and its correlation with the postprandial glycemia.

We found a statistically significant difference between meals accurately and inaccurately counted in terms of postprandial euglycemia. Of meals accurately counted, 55% were followed by an in-target postprandial glucose values, as opposed to only 22% of meals inaccurately counted with in-target postprandial glycemia ($P = .000$). These findings suggest the importance of CHO counting accuracy on normalizing postprandial glucose profile.

Although accuracy of counting showed a statistical significance effect on postprandial glycemia, there were 75 meals accurately counted but were followed by postprandial glucose outside the target range (Table 1). We did not consider GI of the recorded meal in data analysis, and this could be a factor leading to this discrepancy. In support of this assumption are the findings of Prillo et al, who reported that

consuming meals with the same CHO content but a different GI produced clinically significant differences in postprandial blood glucose.[27]

Counting fat and protein in meals is another issue that comes into play when postprandial glycemia is considered. Studies showed that counting fat and protein in addition to the CHO improve glycemia, and it was recommended to include fat and protein in the meal calculation.[28] In our study, we instructed patients to count only CHO content in meals, and no insulin was considered for fat and protein. This might be another factor explaining the discrepancy shown between the number of meals accurately counted and the number associated with out of target postprandial glucose (Table 1).

Apart from CHO amount and type, protein and fact contents of meals, GI, and other variables influence postprandial glycemia. We postulate that preprandial blood glucose levels, meal size and time, sequence of meal ingestion, relation to exercise timing, insulin sensitivity, illness, and stress level can affect postprandial glycemia. In this regard, there are well-known determining factors of postprandial glycemia. One of those is the timing of insulin administration in relation to the meal ingestion. Cobry et al showed that an insulin bolus 20 minutes prior to a meal results in a significantly better postprandial glucose control compared with an insulin bolus given just prior to or after meal.[29] We did not assess the timing of insulin blousing in relation to meals in this study. In addition, delayed gastric emptying is an important factor that has been seen in children with long-standing diabetes.[30]

Overall, while CHO counting is a useful method to estimate prandial insulin, it is associated with a considerable degree of complexity. The complexity is 2-fold. One is related to the accuracy issue and how to attain it, and the other is related to the confounding factors affecting the postprandial glycemia. Further studies with more robust designs to consider GI, load, fat, and protein contents are required.

Conclusion

We conclude that accuracy of CHO counting is an important determining factor of postprandial hypoglycemia. However, other factors should be considered when advising on prandial insulin calculation and adjustment. Underestimating and overestimating the CHO content of meals lead to postprandial hyperglycemia and hypoglycemia, respectively, with no significant effect of the meal size.

Abbreviations

CHO, carbohydrate; DCCT, Diabetes Control and Complications Trial; GEE, generalized estimating equations; GI, glycemic index.

Declaration of Conflicting Interests

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