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Carbohydrate Counting: How Accurate Should It Be to Achieve Glycemic Control in Patients on Intensive Insulin Regimens?

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Abstract. Carbohydrate counting is an important meal-planning tool for patients on intensive insulin regimens. Preprandial insulin bolus is adjusted taking into account the carbohydrate content of each meal and the insulin-to-carb ratio of each patient throughout the day. Evidence suggests that accurate carbohydrate counting may have positive effects not only on reducing glycosylated hemoglobin concentration but also on decreasing the incidence of hypoglycemic episodes. Nevertheless, despite its benefits, the efficacy of carbohydrate counting depends on the ability of each patient, or its caregiver, to accurately estimate the carbohydrate content of each meal. Therefore, it is of great importance to understand how accurate should carbohydrate counting be, and the impact of inaccurate carbohydrate counting on the glycemic control of each patient. Within this work, we propose an analytic method that uses the insulin-to-carb ratio and the insulin sensitivity factor, along with the glycemic targets of each patient to calculate the limits of accurate carbohydrate counting, in order to achieve better glycemic control and to reduce hypoglycemic episodes.

INTRODUCTION

Evidence suggests that diet has an important role in diabetes prevention and management. Indeed, patients on intensive insulin regimens widely use diet planning along with carbohydrate counting to control postprandial glycemia [1, 2, 3]. Furthermore, the accuracy of carbohydrate counting is determinant to avoid postprandial hypoglycemic and hyperglycemic episodes [2]. Smart *et al* showed that a variation of about 20 g, above or below a planed meal containing 60 g of carbohydrates, may result in postprandial hyperglycemia or hypoglycemia, respectively [4]. However, a variation of about 10 g in carbohydrate estimation should not have a considerable effect on the postprandial glycemia [5]. Although these limits provide some guidance to those using intensive insulin therapy, they need to be improved. To that end, we propose an analytic method to find the limit to carbohydrate counting error according to each person insulin-to-carb ratio and the insulin sensitivity factor.

MATHEMATICAL METHODS

The insulin bolus for each meal can be calculated using the following equation:

$$B = \left(\frac{CHO}{ICR} + \frac{G - G_T}{ISF}\right) K - IOB, \tag{1}$$

where B is the bolus, CHO are the carbohydrates planned to be consumed in that meal, ICR is the insulin-to-carb ratio (n.b., $ICR > 0$), G is the pre-meal blood glucose, G_T is the pre-meal blood glucose target, ISF is the insulin sensitivity factor (n.b., $ISF > 0$), K is a constant reflecting the physiologic status of the patient, and IOB (Insulin-on-Board) is the insulin remaining active from the previously administrated bolus [6, 7]. In the following analysis, we will consider

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$K = 1$ (i.e., the influence of illness, physical activity or medication on insulin and glucose metabolism of patients is not addressed in this study) and $IOB = 0$ (i.e., the time between meals is higher than the duration of insulin action, and there is no insulin stacking). Furthermore, we also consider that patient's ICR and ISF are physiologically appropriate.

Let $CHO = \hat{CHO} \pm \Delta CHO$ be a variable of Equation 2, where $\hat{CHO}$ is an estimate of CHO with an absolute error $\Delta CHO > 0$, and the other variables of Equation 2 are exact values. So, the absolute error on B is equal to $\Delta B = \left|B - \hat{B}\right|$, where: $B = CHO/ICR + (G - G_T)/ISF$ and $\hat{B} = \hat{CHO}/ICR + (G - G_T)/ISF$. Therefore, we have:

$$\Delta B = \left|\frac{CHO - \hat{CHO}}{ICR}\right| = \frac{\Delta CHO}{ICR}. \tag{2}$$

The absolute error of B, given by Equation 2, will act as an undesired correction bolus, and its effect on the patient blood glucose is:

$$\Delta G = \Delta B \cdot ISF = \frac{ISF}{ICR}\Delta CHO,$$

where ΔG is the variation on the patient postprandial blood glucose, as a result of ΔCHO. By denoting the hyperglycemia and hypoglycemia limits as G_{Hyper} and G_{Hypo}, respectively, it is possible to conclude that the maximum value of ΔG allowed to avoid hyperglycemia and hypoglycemia episodes is given by $\min\left\{G_{Hyper} - G_T, G_T - G_{Hypo}\right\}$[1] and, therefore, the maximum value of ΔCHO, i.e., ΔCHO_{max}, is given by:

$$\Delta CHO_{max} = \frac{ICR}{ISF} \cdot \min\left\{G_{Hyper} - G_T, G_T - G_{Hypo}\right\}. \tag{3}$$

By using Equation 3, it is possible to find personalized limits of accurate carbohydrate counting according to each patient data. Such tailored limits may have a decisive influence in order to achieve better glycemic control, reducing the frequency of hyperglycemia and hypoglycemia episodes and glycemic variability.

DISCUSSION

Several studies show that patients with diabetes underestimate carbohydrate counting fearing hypoglycemic episodes, as a consequence, they have high levels of HbA1C [8, 9]. Nevertheless, such worrying could be relieved if patients are aware of their limits. For this purpose, we can use Equation 3, where the maximum admissible absolute error while counting carbohydrates depends on the ICR, the ISF, and the glycemic targets of each patient. To assess the proposed method, we will consider a hypothetical patient of 75 kg body weight, taking a total of 50 U of insulin per day, having the following glycemic targets, $G_{Hyper} = 150$ mg/dL, $G_{Hypo} = 70$ mg/dL, and $G_T = 110$ mg/dL. Regarding the ICR and ISF values for that patient, they were obtained using the rules reported by King *et al* in [10] and by Grunberger *et al* in [11], as presented in Table 1 and pictured in Figure 1.

By using Equation 3 to calculate the maximum admissible absolute error that our hypothetical patient can commit while counting carbohydrates, and considering the arithmetic means of ICR and ISF found in Table 1, one find the value of:

$$\Delta CHO_{max} \approx \frac{8.33}{34.14} \cdot \min\{150 - 110, 110 - 70\} \approx 9.76\,\text{g}.$$

Therefore, according to the method proposed in this work, it is reasonable to argue that the maximum absolute error that our hypothetical patient can commit while estimating the carbohydrate content of each meal is approximately 10 g. This result corroborate the findings presented in [4, 5] by Smart *et al* for a pediatric population, and also with the results presented in [9, 12] for an adult population with T1DM. For patients with T2DM, the limits for accurate carbohydrate counting could be more permissive as demonstrated in Figure 1, since they have lower ISF values due to insulin resistance.

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[1] The function $\min\{\cdot\}$ returns the minimum value of a set of elements.

TABLE 1. The maximum admissible absolute error while counting carbohydrates, i.e., ΔCHO_{max}, for different values of ICR and ISF according to the rules reported in [10, 11].

ICR rule	ICR (g/U)	ISF rule	ISF (mg/dL/U)	ΔCHO_{max} (g)
$(2.8 \times BW\,\text{lb})/TDD$	9.26	$1724/TDD$	34.48	10.74
$441/TDD$	8.82	$1694/TDD$	33.88	10.41
$(2.8 \times BW\,\text{lb})/TDD$	9.26	$1694/TDD$	33.88	10.93
$(2.6 \times BW\,\text{lb})/TDD$	8.60	$1960/TDD$	39.20	8.77
$(217/TDD) + 3$	7.34	$(1076/TDD) + 12$	33.52	8.76
$300/TDD$	6.00	$1500/TDD$	30.00	8.00
$450/TDD$	9.00	$1700/TDD$	34.00	10.59
Arithmetic mean:	**8.33**		**34.14**	

Note:
TDD is the Total Daily Dose of insulin, BW is the patient body weight, and U means units of insulin.
To calculate ICR, ISF, and ΔCHO_{max} were used the following values:
$TDD = 50\,\text{U}$, $BW = 75\,\text{kg}$, $G_{Hyper} = 150\,\text{mg/dL}$, $G_{Hypo} = 70\,\text{mg/dL}$, and $G_T = 110\,\text{mg/dL}$.

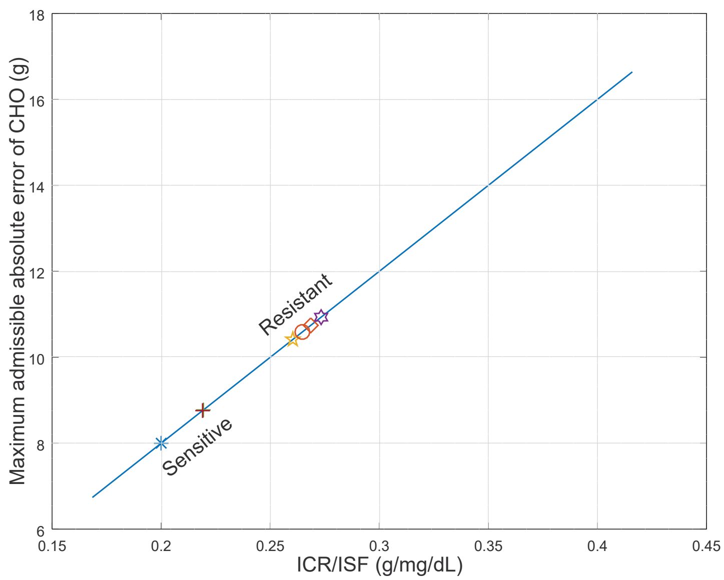

FIGURE 1. The maximum admissible absolute error while counting carbohydrates, i.e., ΔCHO_{max}, as a function of ICR/ISF.

CONCLUSION

Carbohydrate counting is a well established meal-planing approach used by patients on intensive insulin regimens to improve their glycemic control. Such patients adjust their preprandial insulin bolus taking into account an estimate of the carbohydrate content of each meal. Evidence suggests that the accuracy of such estimate is vital to reduce glycemic variability and avoid hyper and hypoglycemic episodes. Indeed, several studies brought to light some limits to accurate carbohydrate counting. Although such limits give important guidance to those using intensive insulin regimens, they need to be improved and better understood by each patient. To that end, this work proposed a new analytic method that uses personalized data (i.e., the insulin-to-carb ratio, the insulin sensitivity factor, and the glycemic targets of each patient) to find the maximum absolute error that each patient can commit while estimating the carbohydrate content of each meal. The proposed method was assessed using data from the literature and the results obtained are in line with the most recent outcomes. Therefore, the proposed method allows patients with T1DM to be more confident when using carbohydrate counting, as they are aware of their limits. For those with T2DM, or having insulin resistance, the absolute error performed when counting carbohydrates could be higher and the risk of hypoglycemic events is reduced when compared with T1DM patients.

CONFLICT OF INTEREST

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