Original Article

Official Journal of Erciyes University Faculty of Medicine

DOI: 10.14744/cpr.2025.33298
J Clin Pract Res 2025;47(3):316–327

The Effects of Carbohydrate Counting Over Glycometabolic Control in Patients Diagnosed with Type 1 Diabetes Mellitus

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ABSTRACT

Objective: Advanced carbohydrate counting (CC), a nutritional intervention that adjusts insulin based on the estimated carbohydrate content of meals, has shown inconsistent effects on glycometabolic control. This study aimed to evaluate the long-term efficacy of advanced CC in patients with type 1 diabetes mellitus (DM) and assess adherence and consistency rates.

Materials and Methods: Adult patients diagnosed with type 1 DM who applied multiple dose insulin therapy were included. Data from patients who completed advanced CC training and practiced it for at least 3 months were retrospectively reviewed. Baseline demographic data, as well as BMI, HbA1c, lipid profile, daily insulin doses, meal frequency, hospital visits, and chronic complication rates, were evaluated before and after CC.

Results: Twenty-five patients (mean±SD age: 22.6±7.7 years, 68% female) were included. The duration of CC was a median (IQR) of 40 (12-75) months. HbA1c levels significantly improved (p=0.023), while BMIs and lipid parameters remained similar. Four patients experienced diabetic ketoacidosis in the year before starting CC and none during follow-up (p=0.046). None of the patients had new-onset diabetic complications during CC. The adherence rate was 69.5%, and the discontinuation rate was 32%. The primary reason for discontinuation was the difficulty in implementing the method daily.

Conclusion: Advanced CC is effective for improving glycemic control in patients with type 1 DM, with effects that last for a long time. Consistency may be hindered for some patients by difficulties integrating it into their daily life. Dietary and lifestyle advice should be individualized in patients with type 1 DM.

Keywords: Carbohydrate counting, diabetes complications, diabetic diet, insulin, type 1 diabetes.

Cite this article as:
Hacioglu A, Uzun I, Karaca Z. The Effects of Carbohydrate Counting Over Glycometabolic Control in Patients Diagnosed with Type 1 Diabetes Mellitus. JClinPractRes2025;47(3):316–327.

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Submitted: 19.02.2025
Revised: 21.02.2025
Accepted: 03.06.2025
Available Online: 17.06.2025

Erciyes University Faculty of Medicine Publications - Available online at www.jcpres.com

INTRODUCTION

Type 1 diabetes mellitus (DM) is an immune-mediated disease characterized by permanent destruction of pancreatic beta-cells and the loss of endogenous insulin production.[1] Its incidence generally peaks during childhood and adolescence; however, new-onset type 1 DM may occur across all ages.[2] The estimated global prevalence was approximately 9 million in 2017, with patients aged 40 to 64 years accounting for 43% of the prevalent cases.[3] The incidence and prevalence vary between countries, with an increasing trend over the years in many of them.[2] Complications of type 1 DM lead to significant morbidity and increased mortality rates, and maintaining good glycemic control is of utmost importance to reduce complication rates.[2,4] To achieve treatment goals in a patient with type 1 DM, it is necessary to balance diet, physical activity, and insulin administration.[5]

Carbohydrates have the greatest effect on post-prandial blood glucose levels,[6] and concerns about the carbohydrate content in diet emerged soon after insulin discovery in the 1920s.[7] Carbohydrate counting (CC) is a dietary management strategy based on the administration of short-acting insulin according to the estimated carbohydrate content of meals.[8] There has been an increasing number of studies on CC since it was reported as one of the nutritional interventions that help achieve glucose goals in the Diabetes Control and Complications Trial (DCCT) trial.[8] A significant improvement in glucose regulation with CC was observed in some randomized controlled studies,[9–11] and the method was recommended for patients with type 1 DM.[12] However, not all authors reported favorable results after CC, and some prospective studies found no changes in HbA1c levels.[13,14] Moreover, there is a paucity of studies reporting the long-term effects of CC on glucose regulation.

The method of carbohydrate counting requires a training period to learn the carbohydrate content of food and adjust preprandial insulin doses.[15] Carbohydrate counting can be classified as basic and advanced according to learning objectives and complexity.[16] Basic CC is based on estimating the carbohydrate content of a meal and consuming consistent amounts while also considering the type and timing of intake to achieve glycemic control. On the other hand, advanced CC not only includes training in estimating the carbohydrate content of food but also involves adjusting insulin doses based on carbohydrate intake using calculation methods such as the carbohydrate-to-insulin ratio and insulin correction factor.[16] In this sense, advanced CC is a more complex method that requires a longer training period. It was reported that providing further education contributed to glucose regulation.[10] However, an increase in the complexity of the method may negatively impact adherence rates,[17] and the success of nutritional interventions relies on adherence and consistency.[5]

The aim of the study was to contribute the literature in terms of the efficacy of advanced CC on glycometabolic control during long-term follow-up in patients diagnosed with type 1 DM. Additionally, we aimed to investigate the rates of adherence and consistency during the long term and the factors that cause patients to quit CC.

KEY MESSAGES

- Advanced carbohydrate counting is an effective method for improving HbA1c levels in the long term in patients with type 1 diabetes mellitus
- Difficulty integrating the method into daily life was the main reason for quitting.
- As advanced CC may not be sustainable for all patients, strategies for training patients on diet and insulin treatment should be individualized.

METHODS

The patients' records were reviewed retrospectively from June 2011 to July 2024. Patients older than 18 years, diagnosed with type 1 DM, and who applied multiple dose insulin therapy were included. Only patients who completed the educational consultations in advanced CC and who practiced it for at least 3 months were included.

The endocrinologist first introduced CC during routine clinic visits. Patients interested in adopting it were referred to a trained dietitian, who provided nutritional consultations in three levels.[15] In the first level, patients were introduced to the carbohydrate content of various foods and provided with a list detailing their carbohydrate amounts. The carbohydrate content of a meal was estimated as the total carbohydrate amount of each food item based on the reference list or food labels. The second level covered the effects of protein, fats, and fiber on blood glucose, the relationship between food, activity, and glucose levels, and self-management strategies. Patients also received dietary advice tailored to their BMI, activity level, and daily nutritional needs. After glycemic regulation by the endocrinologist, patients recorded their food intake for 3 days in an outpatient setting, and the total daily insulin dose was estimated. At the third level, patients learned carbohydrate-to-insulin ratios (CIR) and insulin correction factors (CF) and how to apply them in preprandial insulin dosing.[15] The 400/500 Rule System was practiced to calculate CIR (550/total daily insulin dose) and CF (1700/total daily insulin dose).[18] Additionally, the third level included training on reading food labels, focusing on calories and ingredients. After completing the three levels, patients recorded their food intake and calculations and administered insulin doses. They were scheduled for a follow-up visit in 3 days, then every 3 to 5 days for two weeks for further adjustments. A dietitian assessed calculation accuracy, while an endocrinologist adjusted basal and bolus insulin doses. Patients who accurately followed advanced CC for at least 3 months were included in the study.

Patients with types of diabetes mellitus other than type 1, those with eating disorders, those who practiced CC only during pregnancy or breastfeeding, and those who did not attend regular clinic visits or had missing data were excluded. Additionally, patients using premix insulin preparations were excluded.

Patients' charts and the electronic database system, with records dating back to 2011, were retrospectively reviewed for demographic data, education level (elementary school, high school, or university graduate), duration of type 1 DM and CC, and comorbid diseases. Dietary habits, including adherence to a specific diet, meal, and snack frequency, and the regularity of diet and insulin use, were recorded before and during CC. Data on adherence to CC was obtained from notes taken during patients' visits. Patients self-reported adherence based on categorical scale such as 'always, most of the time, half of the time, less than half, never'. It was also recorded whether the patient exercised regularly before and during CC or started an exercise program along with CC, as this could interfere with diabetes regulation.

To assess glycometabolic control, BMI, serum HbA1c levels, and lipid profile (total cholesterol, low-density lipoprotein cholesterol [LDL-C], high-density lipoprotein cholesterol [HDL-C], triglycerides), hospitalization rates due to diabetic ketoacidosis, and the rate of chronic complications were evaluated before and after CC. Daily insulin doses per kilogram of body weight and hospital visits were compared before and after follow-up with CC. The number of meals per day includes both main meals and snacks.

Serum total cholesterol, HDL-C, and triglycerides were measured by spectrophotometric enzymatic method (Cobas; Roche Diagnostics, Mannheim, Germany), and Friedewald formula was used to calculate LDL-C level. HbA1c was measured by immunoturbidimetric method (Cobas; Roche Diagnostics, Mannheim, Germany). The diagnosis of diabetic ketoacidosis and chronic complications secondary to DM were established according to relevant guidelines.[19–21]

The study was approved by the Ethics Committee of Erciyes University School of Medicine (date: 21.08.2024, number: 2024/138) This study was conducted in accordance with the Declaration of Helsinki.

Statistics

SPSS 26.0 (Armonk, NY: IBM Corp) was used for statistical analysis. Normality of the data was assessed using visual (histogram) and analytical (Shapiro-Wilk test) methods. Student t-tests and Mann-Whitney U tests were used to compare different groups based on the normality of the data. The data from related samples before and after CC were analyzed using paired sample t-tests and Wilcoxon signed-rank tests. Fisher's exact test or Pearson's chi-square test was used for the analysis of categorical variables depending on sample size. Spearman analysis was used to investigate correlations between variables. The statistically significant level for p-value was <0.05.

RESULTS

Patients

Twenty-five patients, 17 (68%) females were included in the study. The mean age at the start of CC was 22.6±7.7 years. The median (IQR) age at the diagnosis of type 1 diabetes mellitus was 13 years (5.5–15.5), and the duration of diabetes until the start of CC was median (IQR) 132 months (54–198). The mean age of diagnosis, age at the start of CC, duration of diabetes until CC, and BMIs as well as HbA1c levels, lipid profiles, and total insulin doses (U/kg/day) were similar between male and female patients. All patients were using multiple daily injections of insulin therapy, with a long-acting basal insulin and a short-acting bolus insulin, before and during CC. Before CC, all patients were administered fixed insulin doses, which were adjusted at the outpatient endocrinology clinic based on preprandial blood glucose levels.

Eleven patients had comorbid conditions: Hashimoto thyroiditis in 4 (with Celiac disease in 1), asthma in 2, epilepsy in 1, congenital retinal dystrophy in 1, multiple sclerosis in 1, and hyperlipidemia in 2. Twelve patients (48%) had diabetes-related chronic microvascular complications before CC. Nephropathy was present in seven patients, neuropathy in seven, and retinopathy in five; three patients had two complications, and two had three complications. None of the patients had macrovascular diabetic complications.

Seventeen (77.3%) patients were university graduates, three (13.6%) were high school graduates, and two (9.1%) were elementary school graduates. The data was missing regarding the education status of three patients.

Eleven (52.4%) patients declared that they had adhered to their diabetic diet and had their meals at regular times before CC, while 10 (47.6%) did not. The data regarding diet was missing in 4. None of the patients were following a specific type of diet (such as a ketogenic diet, Mediterranean diet, etc.). Four patients were administering insulin irregularly before CC. Five (22.7%) patients were exercising regularly, while 17 (77.3%) practiced no exercise, and the data regarding exercise were missing in 3.

Eight patients had some experience with CC, and 3 of them with insulin pump therapy previously, but they did not continue due to various reasons. These patients underwent the same training program as other patients.

Table 1. Comparison of the parameters regarding glycometabolic control and disease management before and at the end of follow-up after carbohydrate counting

Parameters of glycometabolic control	Before carbohydrate counting	After carbohydrate counting	p
n	25	25	
BMI (kg/m^2)	22.0 (20.9–24.5)	23.7 (21.9–25.7)	0.182
HbA1c (%)	8.9 (7.4–10.6)	7.9 (7.3–8.8)	**0.023**
Total cholesterol (mg/dL)	181.7±35.3	171.6±25.8	0.126
LDL-cholesterol (mg/dL)	99.9±31.1	97.4±23.1	0.363
HDL-cholesterol (mg/dL)	56.8±14.4	57.1±11.6	0.824
Triglyceride (mg/dL)	93.0 (51–324)	84.5 (49–127)	0.300
Number of meals per day	6.0 (3.3–6)	4.0 (3–5.5)	0.056
Insulin dose (U/kg/day)	0.9±0.2	0.7±0.2	0.286
Number of outpatient clinic visits	4.0 (3–5)	4.0 (3–5)	0.383

The data are presented as mean±standard deviation or median and interquartile range (25th–75th percentile) (IQR) according to the distribution. p<0.05 is designated in bold. BMI: Body mass index; LDL: Low-density lipoprotein; HDL: High-density lipoprotein.

Glycometabolic Control and Disease Management Following Carbohydrate Counting

The duration of advanced CC was a median (IQR) of 40 (12–75) months.

The parameters regarding glycometabolic control and those related to disease management before and after CC are presented in Table 1. There was a significant improvement in HbA1c levels (Fig. 1), while BMIs and lipid parameters remained similar (Table 1). Four patients experienced diabetic ketoacidosis during the year before starting CC and none during the follow-up time after CC (p=0.046). None of the patients had new-onset diabetic microvascular or macrovascular complications during CC.

Further analysis was performed based on a disease duration of less than or more than 5 years. Patients with a diabetes duration of <5 years showed no significant improvement in HbA1c levels (from 9.6±2.5 to 8.9±2.2, p=0.454), while those with a duration of ≥5 years showed improvement (from 8.9±1.9 to 7.9±1.1, p=0.023). The age at the start of CC was higher in those with a disease duration of ≥5 years (Table 2). BMI and lipid parameters remained stable in both groups after CC (data not displayed). Self-reported adherence to CC was similar between the groups.

Nineteen (90.5%) patients reported that either the content of their diet or the number of meals changed following CC, while 2 (9.5%) patients reported no change, and data were missing in 4. Five patients reported that their meal times became more flexible after they started CC. Eight patients either reduced the number of snacks they consumed or stopped having them, while three patients started eating snacks. The total number of meals (main meals and snacks) consumed per day decreased after CC, but did not reach statistical significance (Table 1). The number of meals consumed during the day was positively correlated with HbA1c levels after CC (rs = 0.460, p = 0.036). Six patients who were not exercising before CC started exercising along with CC, while five patients who were already exercising continued their routine.

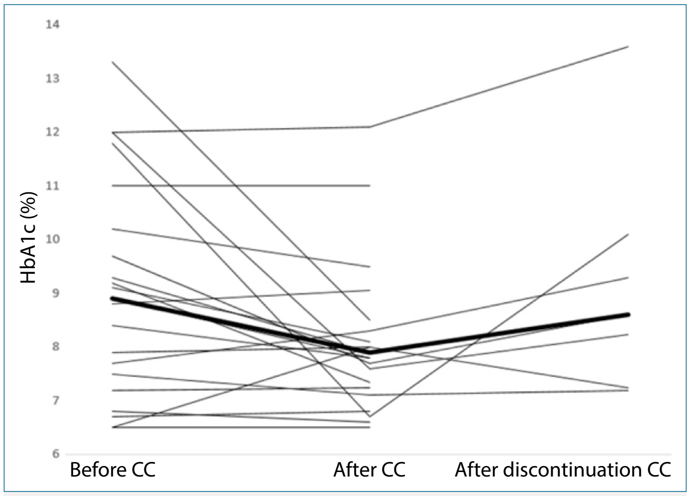

Figure 1. HbA1c levels are presented for each patient before and after carbohydrate counting. The bold line represents the group's mean value. There was a statistically non-significant tendency for an increase in those who discontinued carbohydrate counting.

Nine (39.1%) patients declared that they fully adhered to CC every day, while 7 (30.4%) stated that they practiced it most

Table 2. Comparison of patients with disease duration <5 years vs ≥5 years

	Disease duration of <5 years	Disease duration of ≥5 years	p
n	7	18	
Female/Male (n)	5/2	12/6	0.999
Age at start of CC (years)	18 (14–21)	26 (19–31)	**0.029**
Age of diagnosis (years)	14 (13–19)	10 (4–15)	0.125
Duration of CC (months)	36 (12–96)	44 (12–74)	0.804
BMI (kg/m^2)	23.7 (22.1–26.8)	21.8 (20.9–23.3)	0.101
Education status (n)			
University graduate	6	11	0.477
High-school graduate	1	2	–
Elementary school graduate	0	2	–
Baseline HbA1c (%)	9.6±2.5	8.9±1.9	0.517
HbA1c (%) after CC	8.9±2.2	7.9±1.1	0.176

The data are presented as mean±standard deviation or median (IQR) according to the distribution. p<0.05 is designated in bold. BMI: Body mass index; CC: Carbohydrate counting.

of the time. Seven (30.4%) patients stated that they continued CC but with some irregularities, affecting at least half of their meal times. Patients who adhered to CC were similar in terms of gender, age at diagnosis, age at CC initiation, duration of diabetes, baseline HbA1c, and BMI to those who reported practicing CC irregularly. No data was present regarding adherence in 2 patients.

Factors associated with Carbohydrate Counting Cessation

Seven patients (28%) discontinued CC and returned to fixed-dose insulin therapy; 3 of them previously declared that they applied CC irregularly. Table 3 presents the results of comparative analyses between the patients who discontinued CC and those who maintained it. The median time for CC duration was significantly shorter in those who discontinued.

The median (IQR) HbA1c was 9.7 (7.7–12.0) before CC and decreased to 7.7 (7.2–8.2) at the last visit before discontinuation of CC (p=0.063). There were no significant changes in BMI values and lipid parameters during CC in this group.

The reasons to quit the therapy were recorded as the complexity of the method and difficulties of practicing CC daily in 5, and new-onset psychological problems in 1. The data was missing in 1.

Follow-up Data after Discontinuation of Carbohydrate Counting

The median (IQR) follow-up time after ceasing CC in 7 patients was 42 (26.5–51.0) months. The median (IQR) HbA1c increased from 7.7 (7.2–8.2) after CC was discontinued to 8.6 (7.3–10.1) at the end of the follow-up under a fixed dose, but it did not reach statistical significance (p=0.063) (Fig. 1). Body mass index values, lipid profile, and number of outpatient clinic visits remained similar after ceasing CC. The change in the number of meals per day and daily insulin dose could not be analyzed due to lost data.

DISCUSSION

Patients diagnosed with type 1 DM were analyzed in terms of the effects of advanced CC over glycometabolic control. Patients who practiced CC had a significant decrease in HbA1c levels, while BMI, lipid profile, and daily insulin doses remained similar. The results imply that CC causes a change in dieting, which may contribute to glycemic control. The main reason for ceasing CC was the difficulty in integrating the method regularly into everyday life.

Previous studies reported controversial results regarding the effects of CC on glucose regulation. A literature review was conducted using the keywords ‘type 1 diabetes mellitus’ and ‘carbohydrate counting’ in a PubMed search. Among 770 results, original articles investigating the effects of CC on glycometabolic control in adult patients with type 1 diabetes mellitus are presented in Table 4. Studies with insulin pump therapy were excluded. Some randomized controlled studies documented significant improvements in glycemia,[9–11,22,23] while others did not.[13,14,24–26] A similar discrepancy was evident among meta-analyses. There was a notable decrease in HbA1c levels in some,[27,28] while contrarily, others reported no changes with CC.[29,30] However, heterogeneity among the included studies was a limitation in the meta-analyses that reported no change.[29,30] In the meta-analysis by Bell et al.,[29]

Table 3. Comparison of baseline characteristics between patients who maintained and discontinued CC

	Patients maintaining CC	Patients who discontinued CC	p
n	18	7	–
Female/Male (n)	12/6	5/2	0.999
Age at start of CC (years)	19 (16.3–27.5)	27 (19–31)	0.220
Age of diagnosis (years)	12.5 (4.0–16.8)	13 (7–15)	0.836
Duration of DM until CC (months)	126 (60–183)	204 (48–240)	0.458
BMI (kg/m^2)	22 (20.9–23.7)	22 (21.3–26.2)	0.566
Education status (n)			
University graduate	12	5	0.999
High-school graduate	2	1	–
Elementary school graduate	1	1	–
Microvascular complications (n)	9	3	0.999
HbA1c (%)	8.9 (6.8–9.5)	9.7 (7.7–12.0)	0.255
Total cholesterol (mg/dL)	182 (152–221)	186 (160–195)	0.999
LDL-cholesterol (mg/dL)	101 (69–125.3)	99 (77–116)	0.999
HDL-cholesterol (mg/dL)	53 (38–69)	58 (55–73)	0.328
Triglyceride (mg/dL)	96 (78–126)	90 (77–116)	0.596
Number of meals per day	6 (3.8–6)	6 (2.8–6)	0.904
Insulin dose (U/kg/day)	0.8 (0.7–1.1)	0.9 (0.8–1.1)	0.594
Number of outpatient clinic visits	3.5 (3–5)	4 (4–5)	0.650
Duration of CC (months)	68 (33.5–81.0)	12 (6–15)	**0.006**

The data are presented as mean±standard deviation or median (IQR) according to the distribution. p<0.05 is designated in bold. BMI: Body mass index; CC: Carbohydrate counting; DM: diabetes mellitus; LDL: Low-density lipoprotein; HDL: High-density lipoprotein.

a further analysis was performed, including studies with a similar methodology, and there was an improvement in HbA1c levels. Similarly, in the subgroup analysis, including studies with low heterogeneity, Builes-Montano et al.[30] reported significant reductions in HbA1c levels with CC compared to usual diabetes education. The results of the present study, though including a small number of patients, aligned with previous findings that reported improvements in HbA1c levels. The median duration of CC in the study was 40 months, which was a longer follow-up period compared to most previous studies.[9–11,14,26,31] HbA1c levels remained significantly improved despite the long duration of CC, suggesting that CC may have lasting effects on glucose control. Additionally, four patients were hospitalized for diabetic ketoacidosis in the year prior to CC. However, none of the patients experienced DKA during the median 40 months of CC, indicating an improvement in glycemic control.

Witkow et al.[23] observed a greater improvement in HbA1c levels among patients with diabetes duration of less than 5 years, which contrasts with our results. While the age of these groups was not reported, the mean age (range) of the whole group was 43.1 (18–74). In comparison to this study, the mean age of our patients was 22.6 years, and the patients with a disease duration of <5 years were significantly younger at the start of CC than those with a disease duration of ≥5 years (median 18 vs. 26, respectively) (Table 2). Adolescence is a period associated with poor glycemic regulation,[32] which might have affected the results in our cohort. One may discuss that the adherence to CC among adolescents was worse than that of older patients. Self-reported adherence rates were similar between the groups in the study. However, studies with larger patient groups utilizing objective adherence measures are needed to conclude this issue.

There was no significant change in BMIs, lipid profile, and daily insulin doses in the study. BMI and daily insulin doses are influenced by the amount of food intake. As advanced CC offers flexibility in food choices, it may lead to increased food intake and BMI.[36] The recommendations for a balanced diet based on weight and physical activity during the CC training process, along with follow-up thereafter, may have

Table 4. Studies investigating carbohydrate counting and glycometabolic control in adults with type 1 diabetes mellitus

Author, year, study design	Study group	Follow-up duration	Effects of CC on glycometabolic control		Additional comments
			HbA1c	BMI & Lipid profile	
Kalergis et al., 2001[14] Randomized prospective cross-over study	Patients n=15, age: 38 (23-59) years, F(n=9) Compared strategies; QUANT: Carbohydrate counting group QUAL: Qualitative adjustment of insulin for food SIMP: No self-adjustment of insulin	3.5 months	Improved in all strategies compared to baseline	No change	- There were no statistically significant differences in metabolic control, quality of life and self-efficacy between the three strategies
DAFNE Study Group, 2002[9] Randomized controlled trial	Study group n=169, age: 40±9 years, F (n=76) Randomization; - Immediate DAFNE (n=84) - Delayed DAFNE (n=85)	12 months	Improved	No change	- The average insulin dose and the number of injections per day increased with CC - Quality of life and the negative impact of diabetes on dietary freedom improved after CC
Scavone et al., 2010[11] Randomized controlled trial	Carbohydrate counting group n=100, age: 39±11 years, F (n=51) Controls (n=156)	9 months	Improved	No change	- Insulin dose requirements decreased and less hypoglycemic events occurred in the CC group
Trento et al., 2011[10] Randomized controlled trial	Carbohydrate counting group n=27, age: 37.3±12.6 years, F (n=9) Controls (n=29)	30 months	Improved	No change	- Quality of life improved in both groups
Schmidt et al., 2012[22] Randomized controlled trial	Carbohydrate counting group n=21, age: 41±10 years, F (n=11) Carbohydrate counting+ABC group n=22, age: 42±10 years, F (n=12) Controls (n=8)	4 months	Improved similarly in both intervention arms	Not available	- Treatment satisfaction improved in both intervention arms, most pronounced in the carbohydrate counting+ABC group
Son et al., 2014[24] Prospective controlled study	Carbohydrate counting group n=22, age: 29.2±2.1 years, F (n=14) Controls (n=15)	6 months	No change	No change	- Quality of life increased in the CC group - Total insulin dose decreased with CC

Table 4 (cont). Studies investigating carbohydrate counting and glycometabolic control in adults with type 1 diabetes mellitus

Author, year, study design	Study group	Follow-up duration	Effects of CC on glycometabolic control		Additional comments
			HbA1c	BMI & Lipid profile	
Ásbjörnsdóttir et al., 2016[33] Retrospective study	Patients (only pregnant women) N=92 Carbohydrate counting group n=41, age: 32±5 years Controls (n=51)	Not relevant	Improved	Not available	- Carbohydrate consumption and glycemic index score were lower in the CC group without increased hypoglycemic episodes
Centenaro et al., 2023[31] Retrospective cohort study	Carbohydrate counting group n=49, age: 32.9±11.3 years, F (n=29) Controls (n=180)	105 (43–198) weeks	Improved	Not available	- CC has favorable effects on HbA1c with a longer follow-up time - Body weight variation was lower in the CC group
Witkow et al., 2023[23] Randomized controlled trial	Regular carbohydrate counting group n=41, age: 40.9±15.5 years, F (n=23) Simple carbohydrate counting group n=44, age: 45.3±18 years, F (n=17)	6 months	Improved in both groups	Not available	- Simple CC was non-inferior to the standard method of regular CC
Uliana et al., 2023[34] Cross-sectional study	Patients N=173, age: 25-44 years, F (84.4%) Subgroups; Carbohydrate counting group (n=126) Controls (n=47)	Not relevant	Adequate HbA1c was associated with CC	Not available	- 'Having practiced CC but not currently practicing it' was associated with an increased HbA1c
Jelleryd et al., 2023[35] Cross-sectional study	Carbohydrate counting group n=58, age: 17.9±4.9 years, F (n=29) Controls (n=53)	9.3±0.6 years	No change	Not available	- Advanced carbohydrate counting is well used after long durations of disease
Isaksson et al., 2023[25] Prospective randomized controlled study	Carbohydrate counting group n=53, age: 49.1±11.9 years, F (n=31) Food-based approach group n=51, age: 47.7±11.5 years, F (n=27) Controls (n=55)	12 months	Similar improvement rates between three strategies	No change	- No differences in quality of life
Ewers et al., 2024[13] Randomized controlled trial	Basic carbohydrate counting (BCC) group n=20 Advanced carbohydrate counting (ACC) group n=21 Controls (n=22)	6 months	No change in BCC or ACC groups compared to controls	No change	- There was no advantage of BCC or ACC over individualized dietary counseling for glycemic control - Dietary educational approaches should be individualized

ABC: Automated bolus calculator, BMI: Body mass index, F: Female.

contributed to the stable BMI observed in the study. Similar to our results, most randomized controlled studies reported stable BMI values after CC.[9–11,13,14,24] A small decrease in BMI was reported in one prospective controlled study, although all patients received similar dietary recommendations. The authors commented that CC might have caused some additional improvements in terms of nutrition and physical activity.[37] The data regarding daily insulin doses were also variable across studies; most reported no change,[10,26,30,31] while some reported an increase,[9] and others reported a decrease.[11] Additionally, lipid profiles generally remained similar across many studies.[9–11,13,14,24,25,30] Carbohydrate counting is a complex process that occurs during both training and follow-up, and the outcome depends on various factors related to both the patient and the healthcare provider. This fact, along with heterogeneous methodology, may explain the differing results between studies.

The number of meals per day showed a decrease, however, not reaching a statistical significance, which may be a result of the small cohort. Carbohydrate counting led to more flexible dieting, along with an increase in the perception of dietary freedom and quality of life, in a prospective controlled study.[9] Our results support the fact that CC leads to changes in dietary habits. As the study was retrospective, satisfaction or quality of life could not be evaluated; however, 90% of the patients declared a change in dieting, and five had a more flexible meal routine after CC.

The rate of patients who fully or mostly adhered to CC was 69.5% in the cohort. A recent study with a comparable methodology reported a similar adherence rate of 69%.[31] Various methods have been used to assess patient compliance with CC. In our study, the data was based on patients' categorical statements, which may have certain limitations. On the other hand, digital tools such as mobile phone-based systems and glucose monitoring technologies may enhance the accuracy of CC, as well as adherence, thereby contributing to improved glycemic control.[38,39] Secher et al.[39] reported better HbA1c levels, higher patient satisfaction, and lower discontinuation rates in patients who used flash glucose monitoring in combination with carbohydrate counting compared to those who did not. None of our patients used any digital tools to facilitate CC; however, the increasing everyday use of digital technologies appears promising in supporting CC and improving metabolic control.

Approximately one-third of the patients quit CC after a median duration of 12 months. Half of them had previously reported irregular application of CC. The main reason for discontinuation was the difficulty of integrating CC into everyday life. Kalergis et al.[14] reported that patients preferred less complex methods, such as the qualitative approach, over quantitative CC. Advanced CC, investigated in this study, was perceived as complex by some patients, and they were unwilling to continue. It was reported that lower education status might negatively affect carbohydrate counting.[40] The majority of the patients (77%) willing to have CC training were university graduates in our cohort. However, the level of education was not a significant factor in the study's discontinuation, although the small number of patients may be a limitation.

On the other hand, both lower and higher-educated patients benefited from CC in terms of glycemic improvement in a randomized study.[23] We could not find any factors that predict long-term consistency in CC. There was an increase in HbA1c levels after ceasing CC, though non-significant, implying that it had a favorable effect over glycemic control during its application.

The main limitations of the study originated from its retrospective design. Exercising, which may have affected glucose regulation, was recorded categorically, and there was no data regarding changes in intensity. It was not possible to isolate the effects of physical activity on glucose regulation. The number of outpatient clinic visits was similar before and after CC. However, short visits when patients apply for insulin adjustments were not routinely recorded in the electronic database system, and we are not aware of the number and the impact of these short visits on glucose regulation. The competency of the patients in terms of the accuracy of CC was not systematically measured due to the retrospective design. However, all patients were closely followed for any mistakes in CC during follow-up. Another limitation was the absence of a control group to compare metabolic variables between patients on CC and those managed with standard dietary and insulin recommendations. Lastly, it is important to note that the study results reflect data from the patients who were willing to undergo CC training and subsequent follow-ups. Given its complexity and training requirements, advanced CC may not be a suitable nutritional intervention for all patients diagnosed with type 1 DM.

CONCLUSION

In conclusion, advanced carbohydrate counting is an effective method for improving glycemic control in patients with type 1 DM, with effects that last for a long time. However, since adherence and sustainability may be negatively affected by concerns about its complexity and difficulty integrating it into daily life for some patients, CC may not be suitable for broader populations. Dietary and lifestyle advice should be individualized in patients diagnosed with type 1 DM.

Ethics Committee Approval: The Erciyes University Ethics Committee granted approval for this study (date: 21.08.2024, number: 2024/138).

Informed Consent: Informed consent was waived due to the retrospective design and use of anonymized data.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Use of AI for Writing Assistance: Not declared.

Author Contributions: Concept – AH, IU, ZK; Design – AH, IU, ZK; Supervision – AH, IU, ZK; Resource – AH, IU; Materials – AH, IU; Data Collection and/or Processing – AH, IU; Analysis and/or Interpretation – AH; Literature Search – AH; Writing – AH; Critical Reviews – AH, IU, ZK.

Acknowledgments: We thank Elif Elis, the diabetes nurse at the Erciyes University Endocrinology Department, for her invaluable support in patient education and follow-up. Her dedication ensured high-quality patient care, and her records contributed significantly to this study.

Peer-review: Externally peer-reviewed.

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