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Evaluation of carbohydrate counting knowledge among individuals with type 1 diabetes mellitus in Saudi Arabia: a cross-sectional study

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ABSTRACT

Introduction Carbohydrate counting (CC) is an important nutritional strategy to improve glycaemic outcomes among patients with diabetes. Few studies have investigated CC knowledge among individuals with type 1 diabetes mellitus (T1DM) in Saudi Arabia. Therefore, we aimed to evaluate CC knowledge in Saudi adults with T1DM.

Study design and methods A cross-sectional study was conducted between December 2021 and February 2022, including 224 patients with T1DM from the University Diabetes Center, Riyadh. Adults aged ≥18 years, diagnosed with T1DM for >1 year, and residing in Saudi Arabia were included. CC knowledge was assessed using a previously well-studied tool (AdultCarbQuiz), which was translated into Arabic and tested for validity by a group of dieticians. Descriptive statistics were used for data analysis, and bivariate and regression analyses were conducted.

Results The AdultCarbQuiz questionnaire-Arabic version had good validity and reliability (Cronbach's α: 0.87). The CC method was used by 54% of the participants. The mean CC knowledge score was 23.01±7.31. A significant negative linear relationship between the participants' CC knowledge scores, and age and glycated haemoglobin (HbA1c) levels, was revealed by simple regression analysis. Furthermore, significant independent variables related to CC knowledge scores were CC use, HbA1c levels, being taught about CC (>5 times), insulin pump usage and DM duration (≤15 years).

Conclusions Approximately half of the patients used the CC method. The mean CC knowledge scores were better in patients who used the CC method, were more frequently taught about CC, were treated using an insulin pump, and had a shorter DM duration than their counterparts. Therefore, designing and implementing a well-structured nutrition education programme tailored to individuals with diabetes is crucial to provide them with up-to-date dietary information, as well as the necessary knowledge and skills, to improve their outcomes and manage their condition.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Carbohydrate counting (CC) is a meal planning strategy that aids in tracking carbohydrate intake and prandial glycaemia and facilitates flexible food selection without adversely affecting the metabolic outcomes of patients. Previous studies on the efficacy and safety of the CC method in patients with type 1 diabetes mellitus (T1DM) reported a significant reduction in glycated haemoglobin (HbA1c) levels.

⇒ CC is a complex skill that is subject to error among children and young adults with T1DM, as well as their families, and efforts are therefore needed to develop skills and achieve accurate CC by the patients and glycaemic management.

WHAT THIS STUDY ADDS

⇒ The current study is among the first to evaluate CC knowledge in adults with T1DM in Saudi Arabia. The Arabic version of the AdultCarbQuiz questionnaire showed good reliability and validity in evaluating the CC knowledge of Saudi adults with T1DM, and approximately half of the participants intended to use the CC method for diabetes management.

⇒ The CC knowledge scores were significantly higher among participants who used the CC method, were taught about CC ≥5 times, used an insulin pump, had lower HbA1c levels and had a DM duration ≤15 years.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ A well-structured nutrition education programme is needed to provide patients with up-to-date information, as well as the necessary knowledge and skills, to improve their outcomes and manage their condition. A prospective and/or randomised controlled study, using a similar questionnaire, is recommended to assess CC knowledge before and after the nutrition education programme.

INTRODUCTION

Type 1 diabetes mellitus (T1DM) is an autoimmune disease with hyperglycaemia due to insulin deficiency resulting from the loss of pancreatic islet β-cells.[1 2] Approximately 10% of all diabetes mellitus (DM) cases are T1DM, which can affect individuals of all ages but

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usually develops in children or young adults. The causes of T1DM remain unclear but are linked to genetic and environmental factors.[1] Over the past 30 years, the incidence of T1DM has increased in Saudi Arabia (SA).[3] In 2017, more than 35 000 children and adolescents in SA had T1DM, with the highest incidence of 3900 cases.[3 4]

Poor glycaemic management among patients with T1DM can lead to acute hypoglycaemia and long-term macrovascular and microvascular complications.[5] Nutrition therapy is associated with improved glycaemic outcomes.[6 7] One of the nutritional approaches to T1DM emphasises the connection between the number of consumed carbohydrates and insulin dosage. Carbohydrate counting (CC) is a meal planning strategy that aids in tracking carbohydrate intake and prandial glycaemia[8] and facilitates flexible food selection without adversely affecting the metabolic outcomes of patients.[9] It is becoming a more widely accepted method after being used as one of four meal-planning approaches with intensive insulin therapy in the Diabetes Control and Complications Trial in the early 1990s.[10] Consequently, many diabetes centres in SA currently consider intensive insulin therapy part of the routine management of T1DM.[11 12] Therefore, nutrition education programmes were tailored to train dieticians in the use of CC as an education modality for patients with diabetes.

Previous studies have evaluated the efficacy and safety of the CC method in patients with T1DM.[8 13–15] Scavone *et al* reported a significant reduction in glycated haemoglobin (HbA1c) levels, fewer hypoglycaemic events and decreased rapid insulin analogue doses after participants were taught about CC.[8] A meta-analysis of randomised controlled trials showed evidence favouring the use of the CC method and a significant reduction in HbA1c levels compared with that of controls.[13] However, CC is a complex skill that is subject to error among children and young adults with T1DM and their families.[16] Therefore, identifying opportunities to develop CC skills can improve interventions and achieve accurate CC by patients and improved glycaemic management.[16]

Few studies have investigated CC knowledge among individuals with T1DM in SA. A pilot study conducted with 94 Emirati and Omani adults with diabetes showed low scores for knowledge of the carbohydrate content of foods.[17] In addition, a cross-sectional study involving 178 Saudi individuals with DM reported a low level of knowledge about carbohydrate foods.[18] Therefore, this study aimed to evaluate CC knowledge among Saudi adults and to assess the associations between CC knowledge and HbA1c levels and other factors, such as educational level, DM duration, type of insulin therapy, regular follow-up with a dietician and learning and practising the CC method, because these factors may affect carbohydrate estimation knowledge and accuracy.[18–20] We hypothesised that patients with good CC knowledge would have a higher educational level, receive insulin pump therapy, use the CC method and have lower HbA1c levels. An extensive review was conducted to identify an easy, quick and previously tested tool that could assess CC knowledge levels. According to the literature, the AdultCarbQuiz is a self-administered questionnaire with good validity and reliability that was developed to aid healthcare practitioners in rapidly assessing CC knowledge among adults with T1DM.[21] This tool was translated into Arabic and reviewed by expert dieticians for information adequacy and validity prior to its application in this study.[22]

METHODS

Study design and participants

A cross-sectional study was conducted with adults with T1DM who were recruited during routine clinical visits to the University Diabetes Center (UDC) in King Saud University Medical City (Riyadh, SA) between December 2021 and February 2022. This study included adult participants aged ≥18 years who were diagnosed with T1DM for>1 year. Patients who could not read or understand Arabic and those with cognitive impairment were excluded.

Sample size estimation and sampling method

The sample size was estimated as follows: approximately 1000 patients from the UDC had T1DM, and approximately 25% of these patients used the CC method as a meal plan to control DM. The following sample size equation was used: $(n) = Z^2\ pq/d^2$ where the Z value for the 95% CI was 1.96, p was the prevalence of CC method usage (25%), q=1 − p=75%, and d was the margin of error (0.06 (6%)). The required sample size was 200. Furthermore, considering a 15% non-response rate, the target sample size was 230. Six patients with incomplete responses were excluded; therefore, the study included 224 patients. Participants were selected by convenience sampling.

Research instrument

The study questionnaire included (1) sociodemographic information, such as age, sex, educational level and marital status; (2) disease information, such as DM duration, last HbA1c level, type of insulin therapy and DM complications or other diseases and (3) nutrition education questions, such as CC method usage, reasons for using CC, frequency of visits to a dietitian in the past 2 years, and the number of times wherein CC was taught. HbA1c levels were obtained from the patients' records for the last 6 months or less.

In this study, a validated AdultCarbQuiz questionnaire was used to evaluate CC knowledge,[22] with permission from the author. The questionnaire was translated into Arabic and reviewed by Arabic language experts. A panel of nutrition experts, including clinical diabetes dietician experts in CC and academic nutrition faculties, reviewed the translated questionnaire for information adequacy and validity using a scoring sheet that listed each question and required the experts to score each item out of 10 and add further comments where necessary. Questions

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that scored ≤5 were reviewed and modified following the comments, which were mostly associated with linguistic issues. Subsequently, the questionnaire was verified for readability with 20 patients. The participants in this pilot study confirmed that the questionnaire's instructions, layout, length, simplicity in completion and time for completion were appropriate, with no reported issues in understanding the questions.

The AdultCarbQuiz questionnaire comprises 43 items in 6 domains: identifying carbohydrates in commonly consumed foods (19 items), ability to count the carbohydrate content in typical portions of simple foods (6 items), ability to read a nutrition label for carbohydrate content (4 items), understanding the glycaemic targets (4 items), knowledge on hypoglycaemia prevention and treatment using carbohydrate foods (5 items) and ability to sum up the carbohydrate content of a meal (4 items). Scores were 1, 0 and 43 for a correct response, incorrect response and overall score, respectively. The 'don't know' answers were scored as incorrect.

Data analysis

Data were analysed using IBM SPSS for Windows V.26.0 (IBM). Descriptive statistics (frequencies, percentages, means and SD) were used to define categorical and quantitative variables. Bivariate analysis was performed using Student's t-test for independent samples and one-way analysis of variance followed by Tukey's test to compare the mean CC knowledge scores of categorical variables with two or more categories. Simple and multiple regression analyses were performed to measure the linear relationships between quantitative dependent variables (CC knowledge scores) and a set of independent categorical and quantitative variables. For categorical independent variables with more than two categories, (k-1) dummy variables were included in the model. Regression coefficients of the model were used to assess how changes in each independent variable affected the CC knowledge scores. In addition, tolerance and variance inflation factor (VIF) criteria were used to evaluate the model's multicollinearity of independent variables. The coefficient of variation (R^2) value was used to quantify the change in CC knowledge scores that were explained by the significant independent variables in the model. The reliability of the tool's Arabic version was assessed by split-half reliability using odd-numbered and even-numbered items. The Spearman-Brown correction was applied to correct the reliability coefficient. Internal consistency was used for each of the domains and all the instrument items, and validity was tested by comparing the mean CC knowledge scores regarding the three independent variables. A $p<0.05$ indicated statistical significance.

RESULTS

Sociodemographic and clinical characteristics

Of the 224 patients with T1DM, 40.6% were men and 68.8% were single. The mean patient age was 28.2±7.8 years. More than 60% had a graduate degree, and DM duration was relatively evenly distributed, with 48.7% and 51.3% having ≤15 and >15 years of DM, respectively. The mean HbA1c level was 8.3%±1.4%, with 61.2% showing no associated complications of DM. Notably, most patients (88.4%) used multiple daily insulin injections, and CC was prevalent in 54%. Only 6.3% of the participants had not visited a dietitian in the past 2 years, while 27.2% had visited a dietitian >5 times. Responses to the number of times wherein CC was taught were >5, 3–5 and 1–2 times in 23.7%, 23.2% and 49.6% of the participants, respectively (table 1).

CC knowledge

The CC knowledge questionnaire showed that the frequency of correct responses for food containing carbohydrates was the highest for bread, rice, spaghetti and baked potato, whereas cheese and butter had the lowest correct responses. The highest and lowest percentages of correct responses concerning the grams of carbohydrates present in each serving of food were for a cup of milk and a cup of cooked rice, respectively. Moreover, 67% and 61.2% of the participants could identify the serving size, and grams of carbohydrates in one serving, from the nutrition label, respectively (online supplemental table 1).

The highest and lowest frequencies of correct responses were provided for the questions related to '2 hours postprandial blood glucose level' and 'one carb choice will raise your blood glucose level by how many points?', respectively. Lastly, regarding a meal's carbohydrate content, 25% of the participants identified the grams of carbohydrates in the provided breakfast example, followed by the snack and supper; however, only 4% identified the grams of carbohydrates in the lunch example (online supplemental table 1).

Relationship between CC knowledge and related variables

The responses to the 43 items of the CC knowledge questionnaire were converted into scores, and the mean values were compared across the participants' demographic and clinical characteristics. The bivariate analysis showed significant differences in the mean CC knowledge scores across educational levels, DM duration, type of insulin therapy, CC use, frequency of visits to a dietitian in the past 2 years, and the number of times wherein CC was taught. The mean CC knowledge scores were significantly higher in participants with postgraduate and graduate qualifications than in those with high school qualifications or lower but were similar between participants with ≤15 and >15 years of DM. The scores were significantly higher in participants who used an insulin pump than in those who used multiple daily insulin injections. In addition, the participants who used the CC method had significantly higher mean CC knowledge scores than those who had never used CC. The mean CC knowledge scores were significantly higher in patients who had visited a dietitian >5 and 3–5 times than in those who had visited a dietician

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Table 1 Distribution of sociodemographic and clinical characteristics of patients with T1DM (n=224)

Characteristics	No	(%)
Age (years)*	28.2*	(7.8)
Sex, male	91	(40.6)
Marital status		
Single	154	(68.8)
Married	60	(26.8)
Divorce	10	(4.5)
Educational level		
High school or lower	51	(22.8)
Graduate	149	(66.5)
Postgraduate	24	(10.7)
DM duration (years)		
≤15	109	(48.7)
>15	115	(51.3)
HbA1c levels (%)*	8.3*	(1.4)
DM complications		
No disease	137	(61.2)
Hypertension	22	(9.8)
Dyslipidaemia	42	(18.7)
Diabetic retinopathy	17	(7.6)
Diabetic foot	2	(0.9)
Diabetic nephropathy	13	(5.8)
Diabetic neuropathy	6	(2.7)
Other diseases	42	(18.8)
Type of intensive insulin therapy		
Multiple daily insulin injections	198	(88.4)
Insulin pump	26	(11.6)
CC use		
Yes	121	(54.0)
No	103	(46.0)
Frequency of visits to a dietitian in the past 2 years		
Has not visited a dietitian	14	(6.3)
1–2 times	93	(41.5)
3–5 times	56	(25.0)
>5 times	61	(27.2)
No of times taught about CC		
Never	8	(3.6)
1–2 times	111	(49.6)
3–5 times	52	(23.2)
>5 times	53	(23.7)

*Mean (SD).
CC, carbohydrate counting; DM, diabetes mellitus; HbA1c, glycated haemoglobin; T1DM, type 1 diabetes mellitus.

1–2 times and those who had never visited. Similar results were observed among participants who had been taught about CC >5 and 3–5 times, compared with those who had been taught 1–2 times and those who had never learnt about CC. However, there was no significant difference in the mean CC knowledge scores associated with sex and marital status (table 2).

Table 2 Comparison of the mean CC knowledge scores with the demographic and clinical characteristics of the patients with T1DM

Characteristics	Mean	(SD)	t-value/ F-value	P value
Sex				
Male	23.02	(7.0)	0.015	0.988
Female	23.01	(7.5)		
Marital status				
Single	23.51	(7.0)	2.457	0.088
Married	22.48	(7.7)		
Divorce	18.50	(8.0)		
Educational level				
High school or lower	20.53	(8.2)	4.091	0.018
Graduate	23.62	(7.0)		
Postgraduate	24.54	(5.8)		
DM duration (years)				
≤15	24.36	(7.2)	2.719	0.007
>15	21.74	(7.2)		
Type of insulin therapy				
Multiple daily insulin injections	22.24	(7.3)	−4.578	< 0.0001
Insulin pump	28.92	(3.9)		
CC use				
Yes	25.98	(6.8)	7.332	< 0.0001
No	19.52	(6.3)		
Frequency of visits to a dietitian in the past 2 years				
Has not visited a dietitian	20.0	(6.9)	3.356	0.020
1–2 times	21.72	(6.8)		
3–5 times	24.05	(7.7)		
>5 times	24.72	(7.3)		
No of times taught about CC				
Never taught	17.25	(4.9)	7.938	< 0.0001
1–2 times	21.50	(7.8)		
3–5 times	23.65	(5.6)		
>5 times	26.43	(6.7)		

CC, carbohydrate counting; DM, diabetes mellitus; T1DM, type 1 diabetes mellitus.

The simple regression analysis between CC knowledge scores and participants' age showed a significant negative linear relationship. Conversely, the regression coefficient of age was −0.159, implying that for every 1-year increase in age, the participants' CC knowledge scores decreased

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Table 3 Relationship between CC knowledge scores and the age and HbA1c levels of patients with T1DM by simple regression analysis

Independent variables	Unstandardised coefficients		Standard coefficient			Collinearity Statistics		Model summary	
	B	SE	Beta	t-value	P value	Tolerance	VIF	R^2	P value
Constant	27.485	1.804		15.239	<0.0001				
Age	−0.159	0.062	−0.170	−2.573	0.011	1.00	1.00	0.029	0.011
Constant	35.967	2.885		12.465	<0.0001				
HbA1c levels	−1.561	0.343	−0.292	−4.549	<0.0001	1.00	1.00	0.085	<0.0001

B, unstandardised beta (rate of change per unit time); CC, carbohydrate counting; HbA1c, glycated haemoglobin; R2, coefficient of variation value; T1DM, type 1 diabetes mellitus; VIF, variance inflation factor.

by −0.159 units on average, which was significant. The constant coefficient value of 27.485 indicated that the mean CC knowledge score when age was zero was also significant. The VIF (1.00) and tolerance values (1.00) of this model indicated no collinearity, as both values were below 4 (VIF) and above 0.25 (tolerance). The R^2 value of 0.029 revealed that only 2.9% of the change in CC knowledge scores was explained by the participants' age, which was significant (p=0.011) (table 3).

In addition, the participants' CC knowledge scores and HbA1c levels showed a significant negative linear relationship. The regression coefficient of −1.561 for HbA1c levels indicated that for every one-unit increase in HbA1c levels, the participants' CC knowledge scores decreased by −1.561 units on average, which was significant. Conversely, a constant coefficient value of 35.967 suggested a significant mean CC knowledge score when the HbA1c value was zero. Furthermore, the VIF (1.00) and tolerance values (1.00) of this model indicated no collinearity, as both values were below 4 (VIF) and above 0.25 (tolerance). The R^2 value of 0.085 indicated that approximately 8.5% of the change in CC knowledge scores could be explained by the participants' HbA1c levels, and was significant (p<0.0001) (table 3).

Multiple regression analysis between the quantitative outcome variable (CC knowledge scores) and a set of independent variables was performed. The independent variables included in the model were: age (in years), educational levels (graduate and postgraduate), frequency of visits to a dietitian, being taught about CC, CC use (yes), HbA1c levels, type of insulin therapy (insulin pump usage) and DM duration (≤15 years).

Among the variables included in the model, the significant independent variables were CC use (yes), HbA1c levels (high), being taught about CC (>5 times), type of insulin therapy (insulin pump usage) and DM duration (≤15 years) (table 4). The regression coefficients of the three variables (CC use, being taught about CC (>5 times) and DM duration (≤15 years)) indicated a significant positive relationship with CC knowledge scores. Conversely, the regression coefficients of the other two variables (HbA1c levels and type of insulin therapy (insulin pump usage)) showed a significant negative association with CC knowledge scores. Moreover, the CC knowledge scores increased by 4.641 units, on average, in participants who used CC, compared with those who had never used CC. The CC knowledge scores decreased by −1.039 units, on average, for every 1-unit increase in HbA1c levels. Conversely, the CC knowledge scores increased by 2.555 units, on average, in participants who were taught about CC >5 times, compared with those who had never been taught about CC. CC knowledge increased

Table 4 Independent factors related to the CC knowledge scores of patients with T1DM by multiple linear regression analysis

Independent variables	Unstandardised coefficients		Standard coefficient			Collinearity Statistics		Model summary	
	B	SE	Beta	t-value	P value	Tolerance	VIF	R^2	P value
Constant	27.225	2.800		9.724	<0.0001			0.301	<0.0001
CC use (yes)	4.641	0.898	0.317	5.168	<0.0001	0.851	1.175		
HbA1c levels (high)	−1.039	0.311	−0.194	−3.338	0.001	0.945	1.058		
Being taught about CC (> 5 times)	2.555	1.014	0.149	2.518	0.013	0.917	1.090		
Type of insulin therapy (insulin pump)	3.239	1.388	0.142	2.334	0.021	0.863	1.159		
DM duration (≤15 years)	1.901	0.832	0.130	2.285	0.023	0.986	1.014		

B, unstandardised beta (rate of change per unit time); CC, carbohydrate counting; DM, diabetes mellitus; HbA1c, glycated haemoglobin; R2, coefficient of variation value; T1DM, type 1 diabetes mellitus; VIF, variance inflation factor.

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Table 5 Reliability of each of the six domains and all the items of the AdultCarbQuiz tool

Name of domain	No of items	Cronbach's α (95% CI)	Split-half reliability coefficient with Spearman-Brown correction
Carbohydrate food recognition	19	0.864 (0.836 to 0.888)	
Counting carbohydrates in each of the foods	7	0.899 (0.878 to 0.918)	
Interpreting nutrition labels for carbohydrates	4	0.794 (0.747 to 0.835)	
Glycaemic targets	4	0.488 (0.369 to 0.589)	
Hypoglycaemia prevention and treatment	5	0.577 (0.483 to 0.659)	
Counting carbohydrates in a meal	4	0.815 (0.772 to 0.852)	
All items	43	0.874 (0.849 to 0.896)	
Odd-numbered and even-numbered items			0.865

by 3.239 units, on average, in participants using an insulin pump compared with those using multiple daily insulin injections. For the independent variable, DM duration (≤15 years), the CC knowledge scores increased by 1.901 units, on average, in participants with DM duration ≤15 years compared with those with DM duration >15 years. The collinearity statistics (tolerance and VIF) showed no multicollinearity, as the tolerance and VIF values were not below and above 0.25 and 4, respectively. The R^2 value of 0.301 implied that the five significant independent variables in the model accounted for 30.1% of the change in the CC knowledge scores, which was significant (p<0.0001) (table 4).

Reliability and validity of the CC knowledge questionnaire

The Cronbach's α values for the 6 domains and 43 items indicated an acceptable reliability of 0.874 (0.849, 0.896). The 'glycaemic target' and 'hypoglycaemia prevention and treatment' domains had lower reliabilities, of 0.488 (0.369, 0.589) and 0.577 (0.483, 0.659), respectively. In additiony, with Spearman-Brown prediction correction, the split-half reliability coefficient comparing the odd-numbered to even-numbered items was 0.865, indicating good internal consistency (table 5).

Regarding the questionnaire's validity, the mean CC knowledge score of the 224 participants was 23.01 (SD: 7.31; maximum score: 38). The mean CC knowledge scores were significantly higher in participants who had visited a dietitian >5 and 3–5 times than in those who had visited a dietitian 1–2 times and those who had never visited. In addition, the mean values were significant for participants who had been taught about CC >5 and 3–5 times compared with those who had been taught 1–2 times or never taught about CC. Furthermore, the CC knowledge scores were inversely associated with HbA1c levels, wherein they decreased as the HbA1c levels increased, which was significant. These analyses demonstrated that the CC knowledge questionnaire had adequate validity.

DISCUSSION

This study evaluated CC knowledge in Saudi adults with T1DM. The main findings were (1) approximately half of the participants used the CC method; (2) participants had acceptable mean CC knowledge scores; and (3) the mean CC knowledge scores were significantly higher in participants who used the CC method, were taught about CC ≥5 times, used an insulin pump, had lower HbA1c levels and had DM duration ≤15 years. Furthermore, this study used a previously well-studied tool (AdultCarbQuiz) that was translated into Arabic, reviewed by expert dieticians, and demonstrated good validity and reliability.

The results showed that 54% of the participants intended to use the CC method for DM management, visited a dietician and were frequently taught about the CC method. However, this trend contrasts with other SA studies, in which 18% of participants used the CC method[18] and 19.8% reported visiting a dietitian.[23] The reason for these differences may be that the UDC, where the study was conducted, is a long-established, specialised diabetes centre in Riyadh that provides different services and treatment options for DM management, including intensive insulin therapy with multidisciplinary teams. Furthermore, the mean knowledge score was 23.01±7.3, which is consistent with the mean knowledge score of the original questionnaire (23.9±8.3).[21]

Patients with T1DM should have good knowledge about foods containing carbohydrates and be able to identify the carbohydrate content in each serving size to adjust the meal insulin dose and manage glycaemia. However, accurate CC requires highly developed literacy and numeracy skills and broad nutritional knowledge to estimate portion sizes correctly, read food labels, weigh and measure foods, and determine carbohydrate content.[19] In this study, participants' knowledge was assessed, with correct answers recorded in the carbohydrate food recognition domain for bread, cooked rice and pasta, and baked potatoes. This positive result could be because these food items are among the most consumed in Saudi culture.[24] Conversely, participants could not identify butter and

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cheese, possibly because they were considered dairy products containing carbohydrates, such as milk. In addition, participants could not respond correctly to the grams of carbohydrates per serving. The scale of carbohydrates was measured in grams per cup; however, some dieticians may have used different measurement scales, during the teaching process, for certain foods (such as rice) using spoons, which is easier and more practical for patients. Therefore, patients using CC may need more information on different resources to identify carbohydrate content to answer questions correctly.[25] Overall, 60% of the patients in this study could interpret the carbohydrate nutrition label. A previous study reported that individuals with DM and other chronic diseases were more likely to read labels regularly to control their medical condition.[26 27]

In addition, patients responded correctly to different glycaemic targets and hypoglycaemia prevention and treatment scenarios. This result could be attributed to the availability of a multidisciplinary team at the UDC, which helped improve their knowledge of DM management. However, 20.5% of the participants answered correctly about how many points of blood glucose would be produced after eating a carbohydrate choice. This result may be due to the participants who had never learnt about CC or had difficulty identifying carbohydrate choices. Only a few participants correctly answered about CC per meal, which could be explained by the knowledge and practice gap in teaching the CC method. This drawback should be resolved before committing the patients to CC[21] and could be feasible by engaging the patients in practical, real-life, teaching scenarios.[19] Therefore, ongoing DM education offered by qualified health professionals, particularly for patients receiving intensive insulin therapy, is necessary to achieve optimal results.[14]

In this study, approximately 30% of the change in the CC knowledge scores was explained by the five independent variables in the regression model ($p<0.0001$). Being taught about CC >5 times throughout patients' lives was significantly positively correlated with CC knowledge. Notably, with the use of the CC method, the knowledge scores increased by 4.641 units on average, as compared with not using CC. Therefore, patients with T1DM who intend to perform CC should have more frequent access to qualified dietitians for information on CC and clarification on important issues.[20 28] In addition, the CC knowledge scores decreased by −1.039 units on average for every one-unit increase in HbA1c levels. Consequently, patients with higher CC knowledge scores had better glycaemic control, which is consistent with the findings of previous studies, in which HbA1c levels decreased in patients who used the CC method.[8 14 29] A 2014 meta-analysis showed that 24 of the 27 included studies reported a reduction of 0.2%–1.2% in HbA1c levels after commencing CC.[30] Furthermore, a randomised controlled trial in children with T1DM reported a significant difference in the mean HbA1c levels between the control and CC groups at follow-up, suggesting that the CC method may improve metabolic control in patients with T1DM.[31] CC knowledge increased, on average, by 3.239 units in participants using an insulin pump compared with those using multiple daily dose injections. This trend is expected because patients on insulin pump therapy receive extensive education, advanced skills and frequent follow-up with the healthcare team, including dieticians, to achieve strict glycaemic control while minimising hypoglycaemia risk.[32] Lastly, the analysis revealed that CC knowledge scores increased by 1.901 units, on average, in participants with ≤15 years, compared with those with >15 years, of DM. This finding is validated by previous studies, which reported an inverse relationship between CC and time since DM diagnosis.[33 34] These studies were conducted with youth and children. Contrarily, no association between DM duration and CC was found in adults[20] or adolescents[35] who received intensive insulin therapy.

The current study provides a comprehensive assessment of CC knowledge in Saudi adults with T1DM. Of note, multiple variables were included to support the scores achieved, and a valid and reliable tool suitable for assessing CC knowledge was used. The AdultCarbQuiz questionnaire's Arabic version had good internal reliability (Cronbach's α: 0.87), similar to that of the original questionnaire (0.90).[21] However, this study was limited to adult patients recruited from a single diabetes centre. Therefore, this study should be replicated on a larger scale, which includes a multicentre scenario. Further research involving children and their parents could reveal interesting findings to design early education interventions to promote a better quality of life. The questionnaire was administered once; therefore, additional studies are warranted to establish the stability of CC knowledge. Furthermore, a prospective and/or randomised controlled study using a similar questionnaire is recommended to assess CC knowledge before and after a nutrition education programme.

In conclusion, approximately half of the participants used the CC method. Specifically, the mean CC knowledge scores were higher in participants who used the CC method, were taught about CC≥5 times, used an insulin pump, had lower HbA1c levels and had DM duration ≤15 years.

Dieticians have an important role to play in promoting the use of CC and assessing knowledge and skills before allowing patients with T1DM to take responsibility for their own care. Therefore, designing a well-structured nutrition education programme tailored to individuals with diabetes is crucial to provide them with up-to-date dietary information, and the necessary knowledge and skills to improve their outcomes and manage their condition.

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Online supplementary table – Frequency of participants who answered "**Correctly**" for food items on the AdultCarbQuiz

I. Carbohydrate food recognition		
Does the following food contain carbohydrates?		
Item No.	**Food items**	**n (%)**
1	Bread	215 (96)
2	Breakfast sausages	100 (44)
3	Baked potato	187 (83.5)
4	Regular Maple Syrup	162 (72.3)
5	Cheese	89 (39.7)
6	Low-fat Milk	128 (57.1)
7	Apple juice	155 (69.2)
8	Soda pop (not diet)	173 (77.2)
9	Cooked dried beans (e.g., navy beans, lentils)	155 (69.2)
10	Apple	141 (62.9)
11	Sugar	173 (77.2)
12	Butter	73 (32.6)

13	Cooked rice	207 (92.4)
14	Plain grilled chicken	162 (72.3)
15	Jam	166 (74.1)
16	Cooked spaghetti noodles (no sauce)	191 (85.3)
17	Canned Spaghetti sauce (tomato)	141 (62.9)
18	Hamburger patty	99 (44.2)
19	Honey	155 (69.2)

II. Counting carbohydrates in each of the foods		
How many grams of carbohydrates are in each serving?		
Item No.	**Food items**	**n (%)**
20	1 cup milk	129 (57.6)
21	1 cup pasta	42 (18.8)
22	1 cup cooked rice	32 (14.3)
23	1 cup juice	60 (26.8)
24	1 cup hot cereal	42 (18.8)
25	1 cup cooked dried beans	36 (16.1)
26	1 cup mashed potatoes	44 (19.6)

III. Interpreting nutrition labels for carbohydrate		
Item No.	**Food label questions**	**n (%)**
27	Looking at the Nutrition Facts label to the right, what is the serving size	150 (67)
28	For one serving, how much carbohydrate would you eat, in grams?	137 (61.2)
29	If you ate the whole package, how many cups would you eat?	127 (56.7)
30	If you ate the whole package, how much carbohydrate would you eat, in grams?	11049.1)

IV & V. Glycaemic targets and hypoglycaemia prevention and treatment		
Item No.	**Questions**	**n (%)**
31	Which will make your blood sugar increase: eating three or five carbs?	188 (83.9)
32	A good blood sugar reading just before a meal would be?	189 (84.4)

33	A good blood sugar reading 2 hours after a meal would be?	198 (88.4)
34	One "carb choice" is equal to how many grams of carbohydrates?	97 (43.3)
35	One carb choice will raise your blood sugar by how many points?	46 (20.5)
36	Which of these carb foods will raise your blood sugar the fastest?	184 (82.1)
37	Suppose you were going to mow the grass, which takes about 30 minutes of solid work; by how many points do you expect your blood sugar to reduce?	68 (30.4)
38	You just walked fast for 1 hour and started feeling shaky and nervous. Suppose your blood sugar was 160 before you started walking. What is it now?	180 (80.4)
39	You get a low blood sugar of 50. How many hard candies should you eat to increase your blood sugar by 50 points?	75 (33.5)

VI. Counting carbohydrates in a meal		
Item No.	**How many grams of carbs exist in a whole meal?**	**n (%)**
40	You eat breakfast: 2 eggs 2 Sausage Coffee, black, two cups with artificial sweetener.	56 (25)
41	You eat lunch: 1 sandwich Fruit juice, 600 mL 1 pickled cucumber	9 (4%)
42	You eat a snack: 1 large banana	46 (20.5)
43	You eat supper: Half (4 pieces) of a large pizza Green salad Iced tea	37 (16.5)