

Carbohydrate Counting /Bolus Calculator Mobile Application Improves Time in Range in Adults with Type 1 Diabetes Subjects

Short running Title: Mobile application improves time in range

Sara A. AlBabtain¹, Nora O. AlAfif², Mohammed S. Almehtel^{3,4}, Anwar A. Jammah⁵, Tariq A. Wani⁶, Tarfa A. Aldahham¹, Ramzi A. Ajjan⁷ and Saad H. AlZahrani³

1. Clinical Nutrition Administration, King Fahad Medical City, Riyadh Second Health Cluster, Riyadh 11525, Saudi Arabia; saaalbabtain@kfmc.med.sa; Tarfa.aldahham@gmail.com
2. Department of Community Health Sciences, College of Applied Medical Sciences, King Saud University, Riyadh 11433, Saudi Arabia; nalafeef@ksu.edu.sa
3. Obesity, Endocrine and Metabolism Center, King Fahad Medical City, Riyadh 11525, Saudi Arabia; malmehthel@kfmc.med.sa, shsalzahrani@kfmc.med.sa
4. Division of Endocrinology, University of British Columbia, Vancouver, Canada
5. Endocrinology Division, Department of Medicine, King Saud University. King Saud University Medical City, Riyadh 12372, Saudi Arabia; ajammah@ksu.edu.sa
6. Biostatistician Specialist I, Scientific Writing and Biostatistics Department, Research Center, King Fahad Medical City, Riyadh 11525, Saudi Arabia; tawani@kfmc.med.sa
7. Division of Cardiovascular and Diabetes Research, Leeds Institute for Genetics, Health and Therapeutics, LIGHT Laboratories, University of Leeds, Woodhouse, Leeds LS2 9JT, United Kingdom; R.Ajjan@leeds.ac.uk

Correspondence: Sara A. AlBabtain saaalbabtain@kfmc.med.sa

Twitter Summary: Using a mobile app for carbohydrate counting and bolus calculation improved time in range by 5% without increasing hypoglycemia in adults with type 1 diabetes.

#T1D #DiabetesTech

Keywords: Type 1 diabetes mellitus, hemoglobin A1c, carbohydrate mobile application, carbohydrate counting, glucose monitoring.

Word Count: 4204

Number of tables and figures: 4

Article Highlights:

- Why did we undertake this study?

We aimed to evaluate whether a mobile app for carbohydrate counting and bolus calculation (CHOC-BC) could improve glycemic control in adults with type 1 diabetes.

- What is the specific question we wanted to answer?

Can the CHOC-BC mobile app improve time in range (TIR) without increasing the risk of hypoglycemia or weight gain?

- What did we find?

CHOC-BC users improved TIR by 5%, experienced reduced hyperglycemia, and showed no increase in hypoglycemia or weight gain over 12 weeks.

- What are the implications of our findings?

A mobile CHOC-BC app supports safer, better, improved glucose control in adults with type 1 diabetes.

Abstract

Objective:

To evaluate the effectiveness and safety of a mobile application for CHOC-BC in adults with type 1 diabetes mellitus (T1DM).

Research Design and Methods:

A 12-week randomized controlled trial was conducted at King Fahad Medical City, Riyadh, Saudi Arabia. Adults with T1DM on multiple daily insulin injections and using Libre 2 flash glucose monitors were randomized to either CHOC-BC or conventional treatment. The primary endpoint was time in range (TIR; 70–180 mg/dL).

Results:

A total of 127 participants (70 females) were included; 64 in the intervention group and 63 in the control group with a mean ~~with a mean~~ age of ~~age of~~ s-were ~~s-were~~ 26.56 ± 4.8 and 26.74 ± 6.52 years, respectively. After 3 months, the intervention group achieved better TIR than the control group ($51.20\% \pm 11.61\%$ vs. $46.17\% \pm 13.02\%$; mean difference (MD), 5.03; 95% confidence interval (CI), 0.70–9.36; $p = 0.023$). Application users showed a significant reduction in level 2 time above range ($17.25\% \pm 11.61\%$ vs. $24.10\% \pm 15.74\%$; MD, -6.85 ; 95% CI, -11.70 to -1.99 ; $p = 0.006$). No significant differences were observed in body weight or time below range.

Conclusions:

The CHOC-BC mobile application empowered users to achieve better glycemic control while maintaining a safe profile that avoids hypoglycemia and weight gain.

Introduction

Type 1 diabetes mellitus (T1DM) is the most common chronic disease in children and young adults (1). It accounts for approximately 2% of diabetes cases worldwide, affecting around 9 million individuals (2). To control glycemic levels, insulin, a balanced diet, and regular physical exercise are required (3). The carbohydrate counting (CHOC) method is considered the most reliable strategy for insulin dose estimation relative to meals (4) as it allows greater flexibility in diet and reduces ~~the~~ disease burden ~~in many cases~~ (5,6).

CHOC was adopted in early landmark studies, such as the DCCT, The Diabetes Control and Complications Trial (DCCT) popularized CHOC in 1993 (7), positively impacting. ~~In addition, CHOC use was associated with better~~ glucose control ~~in multiple studies~~ (7,8), while also facilitating ~~and improved impact of diabetes on~~ dietary freedom and better quality of life(9).

Unfortunately, in clinical practice, regular use of CHOC among T1DM is challenging which might impact blood glucose control ~~and variability~~ (10). CHOC is often considered a difficult task for patients, as it requires ~~multiple glucose assessments,~~ carbohydrate estimation in homemade meals, precise reading of food labels, ~~potentially risky decision making,~~ and extensive education (11). Over 59% of people with T1DM do not accurately quantify carbohydrates in their meals (12). Moreover, approximately 50% of patients with diabetes consider CHOC the most challenging aspect of managing their disease (13). As a result, CHOC and insulin dose calculation can be particularly difficult for patients, especially ~~among~~ younger individuals.

The rapid advancement ~~in of DM related~~ technology has helped patients with DM to achieve better glucose control (14). Continuous glucose monitoring (CGM) systems have become highly sophisticated, enabling more accurate blood glucose measurement, while also

predicting ~~blood~~-glucose trends, and ~~interacting with mobile applications that can alert~~ing users ~~about of~~ potential hypoglycemia or hyperglycemia (15). Additionally, coaching applications have also improved, enabling patients to calculate insulin doses more accurately (14).

The CHOC applications facilitate precise carbohydrate calculations for patients by allowing them to easily select the desired food and quantity, instantly computing carbohydrate content and insulin doses based on individual insulin-to-carbohydrate ratio (ICR) and insulin sensitivity factor (ISF) (16). ~~Of note~~Interestingly, people with T1DM believe that technology will improve the CHOC process (17).

~~Moreover, a~~The importance of technology in helping with CHO counting has been shown ~~in a~~ study randomizing 168 adults with ~~T1D poor metabolic control~~ to either a mental calculation group or an automated bolus calculator (ABC) group. The ABC ~~group, which calculates mealtime and correction insulin doses based on individualized parameters after users manually enter carbohydrate content, led to~~has a significantly greater HbA1c reductions after 12 months compared with the mental calculation group.(18). Similarly, a study conducted in Denmark involving 51 adults with T1DM randomized to ~~three groups, namely,~~ Control (n = 8), CarbCount (n = 21), and CarbCountABC (n = 22), ~~has shown significantly lower HbA1c -arms-~~After 16 weeks of follow up, HbA1c levels ~~were significantly lower in the CarbCount group than in the control group, but did not differ significantly between the CarbCount and CarbCountABC groups~~ compared with controls (8). These findings highlight the effectiveness of CHOC applications in optimizing glucose control.

~~However, studies in this area remain limited and frequently use HbA1c for glycemic assessment, rather than CGM-derived metrics that provide a more granular picture of glucose levels~~The cumulative assessment of these studies has highlighted several limitations. First, there

is a strong tendency toward using HbA1c for glucose monitoring, potentially at the expense of CGM systems and ambulatory glucose profile (AGP), a more advanced method for evaluating glycemic control patterns (15). Also, there is a lack of studies investigating Second, the sample size in most studies was small. More importantly, none of the prior research has investigated the efficacy of mobile applications that combine CHOC and bolus correction ~~on DM control~~.

Therefore, our aim was to assess the effectiveness and safety of the carbohydrate counting and bolus calculation (CHOC-BC) mobile application for glucose control among adults with T1DM.

Research Design and Methods

Study Design:

A randomized controlled trial was conducted with two parallel groups. Individuals with T1DM were randomly assigned to use the CHOC-BC application (CHOC-BC intervention group), or conventional treatment (Control group). Computer-based randomization was used to allocate participants to either of the two groups. This study was conducted at the diabetes clinics in King Fahad Medical City (KFMC), Riyadh, KSA. Ethical approval was obtained from the KFMC Institutional Review Board (IRB), log number 22-630. This trial is registered at ClinicalTrials.gov (Identifier: NCT06945744). Recruitment began on May 21, 2023, and the study was completed on December 21, 2023.

Study Subjects:

Individuals were assessed for eligibility at the Obesity, Endocrine, and Metabolism Centre (OEMC). Eligible participants included males and females aged 18–60 years with a clinical diagnosis of T1DM for at least one year and HbA1c levels ($>6.5\%$ [48 mmol/mol])). Participants must be on multiple daily insulin injections, possess basic knowledge of CHOC, and actively use a mobile phone operating on iOS 13 or higher or Android 11 or higher. Furthermore,

participants needed to be active users of the Libre 2 CGM system, with a sensor capture rate of at least 30%.

Exclusion criteria included individuals with limited literacy, insulin pump users, pregnant or breastfeeding women, individuals with ischemic heart disease, and those with multiple comorbidities where hypoglycemia could pose a significant risk. Participants unwilling or unable to comply with the study protocol or those following a very low-carbohydrate diet (<10% daily carbohydrate intake) were also excluded.

Sample Size:

Group sample sizes of 61 in the first group and 61 in the second group achieve 90% power to detect non-inferiority using a one-sided, two-sample t-test. Time in range (TIR) of the CHOC-BC in our setting, is presumed to be more than the Standard calculator, and the higher value of the mean is considered better in our hypothesis. Our non-inferiority testing aims to conclude that CHOC-BC is not appreciably worse than the standard, with a non-inferiority margin of 10 percentage points in TIR% compared with the standard manual CHOC. The true ratio of the means at which the power is evaluated is 1.00. The significance level (alpha) of the test is 0.05. The coefficients of variation of both groups are assumed to be 0.20. The equipoised sample of 70 cases for each arm was enrolled, with the due consent of the patient, to overcome the subsequent 15.0% attrition rate expected during the follow-up period. Patients were allocated to two parallel arms using a Microsoft Excel 16 random sequence generator calculator (19,20).

Study Protocol:

During the initial clinic visit, eligible participants received a comprehensive explanation of the study rationale and completed informed consent forms. Data collection began with

~~comprehensive~~ baseline assessments, including participant interviews and physical

Commented [RA1]: Are you sure it is not superiority that you wanted to look at? What is the point of non-inferiority?

Commented [RA2]: Not sure I understand this.

Commented [RA3]: This is different to the version I had before Saad. Why would you do a non-inferiority study?

measurements. These assessments covered the following: demographics, medical history, anthropometric measures, insulin doses, and detailed documentation of bolus and basal insulin doses, ISF, total daily dose, and ICR, if available. Blood samples were collected from both groups after a minimum 10 hours fasting period. Subsequently, the samples were analyzed for HbA1c and lipid profile, including low-density lipoprotein (LDL), total cholesterol, and triglycerides.

Flash Glucose Monitoring:

The FreeStyle Libre version 2 sensor was used in this study ~~and glycemic data were collected. The AGP report for the last two weeks was recorded as baseline. The outcomes in this study utilized data points from the from~~ LibreView, ~~including AGP. The primary outcome was TIR (70–180 mg/dL). While secondary outcomes included Time Above Range (TAR) (>180 and >250 mg/dL), glucose variability, defined as the percent Coefficient of Variation ((%CV), average glucose (mg/dL), glucose management indicator (GMI%), and HbA1c. Additionally, Time Below Range (TBR) (<70 and <54 mg/dL), number of the low-glucose events and body mass index (BMI) were recorded to ensure the safety of the application. Libre data over 2 weeks before randomization were used as baseline. CGM-derived TIR and TAR. Other Outcomes recorded included bimonthly measurements (TIR and TAR). Flash-glucose monitoring data were also~~ analyzed bi-monthly over 3 months to evaluate early changes in glycemic control ~~in the intervention group. This frequent analysis facilitated close monitoring of participants' progress and the early detection of potential application-related effects on glucose management.~~

~~Participants in both groups used a Libre glucose flash meter for at least 2 weeks before randomization and continued for at least 2 weeks after the intervention group started using the~~

~~application.~~ To minimize the risk of hypoglycemia, participants were instructed to check their ~~blood sugar~~ glucose levels before each meal, 2 hours after meal, and 3 hours after the meal.

Commented [RA4]: Repetitive

Commented [RA5]: Sensor does not measure blood but interstitial tissue glucose.

Dietary Management Plan:

The study involved a comprehensive intervention led by a registered dietitian (PI) who individually educated participants on personalized nutritional plans. The control group ~~followed a standard diabetic diet consisting of~~ used mental CHOC ~~calculations and used the standard way of~~ correction boluses. ~~The clinical dietitian reviewed the concepts of CHOC and reviewed the existing ICR and ISF for both groups. On the other hand, t~~ The intervention group received education ~~on about~~ CHOC-BC mobile application. Both groups were offered the chance to contact the clinical dietitian to relay inquiries about the carbohydrates counting.

Commented [RA6]: What does this mean?

Additionally, the clinical dietitian reviewed and recalculated each participant's ICR using the formula $500/\text{TDD}$ (5) and ISF using the formula $1700/\text{TDD}$ (21) or continued with the previous calculations if the participant already had them. Any inconsistencies between participant and clinical dietitian-calculated values were discussed and reconciled ~~as~~ per physician recommendations.

CHOC-BC Mobile Application:

The CHOC-BC mobile application was developed by a team of endocrinologists and registered dietitians in collaboration with ~~the~~ information technology (IT) ~~department~~. Carbohydrate content for unlabeled foods was obtained following the American Dietetic Association's guidelines (22), while data for restaurant foods were ~~derived from official sources~~. The application also features over 700 different types of foods. To ensure ~~its~~ validity, the application was evaluated by two expert clinical dietitians working at CHOC and the ~~diabetes clinic~~ in KFMC, as part of the IRB approval process. This user-friendly application guides

Commented [RA7]: What does that mean?

Commented [RA8]: Again, what does this mean (how many individuals involved)?

participants through a step-by-step process for calculating insulin boluses. Initially, it requires participants to input their individual ICR, ISF, and target blood glucose levels. For enhanced safety, the application utilizes pre-set ranges for these values to prevent potentially harmful miscalculations. Acceptable ranges were 20–100 mg/dl/unit for ISF, 5–50 g/unit for ICR, and 120–200 mg/dL for target blood sugar level. All entered data were stored within the application with the option for later editing if needed.

Commented [RA9]: Why not more clinically relevant range?

Next, participants input their current blood glucose readings. To prevent hypoglycemia and hyperglycemia, the application automatically rejects values outside the acceptable range (below 80 mg/dL or above 500 mg/dL). It prompts users to correct their blood sugar level before using the application. Finally, users select their desired food items from a predefined list or search for specific items using the search function. Selected items are added to a virtual basket. Upon pressing the “Basket” button, the application calculates the total insulin dose required, including separate values for carbohydrate and correction doses, and presents detailed information for each parameter.

Commented [RA10]: Are you sure this is 500?

To promote participant understanding and ensure safe application utilization, a clinical dietitian guided participants through ~~practical trials with~~ various meals using the CHOC-BC application during ~~the clinic visits~~. The duration of education sessions varied between 1 and 2 hours, tailored to each participant’s knowledge and learning pace. At the end of the visit, the participants in both groups received detailed instruction sheets via WhatsApp for future reference (Supplemental S1).

Virtual Follow-Up:

During the 3 months following the initial visit, the clinical dietitian communicated with the intervention group every 2 weeks (or as needed) to ensure proper application use and address

safety concerns (particularly hypoglycemia risk). Additionally, AGP data were collected every 2 weeks, shared, and discussed with the patient by the dietitian via WhatsApp or voice call. If ~~there were concerns over glucose blood sugar levels became uncontrolled~~, the treating physician was consulted.

Completion Visit:

Upon completion of the 3-month study period, patients in both groups were notified of the requirement for blood tests to assess HbA1c and lipid profile ~~levels~~. Additionally, weight measurements, insulin doses (including basal and bolus), ISF, ICR (if applicable), physical activity levels, and any other relevant information, such as changes in medication or following a new diet, were recorded. Finally, data were downloaded at two-week intervals and 3 months for both groups, which have been used for comparison.

Statistical Analysis:

~~In this work,~~ IBM SPSS Statistics version 28 was used for all statistical analyses, with a p-value of <0.05 being considered statistically significant. Categorical data were presented as frequencies and percentages, while continuous data were summarized using mean values with standard deviations (SDs).

To assess baseline differences between the intervention and control groups, chi-square tests were used for categorical variables, whereas independent-sample t-tests were conducted for normally distributed continuous variables. While comparing baseline data with post-intervention measurements, changes within each group over time were evaluated using ~~the~~ paired-sample t-test for normally distributed continuous variables.

To assess the differences in post intervention outcomes between the intervention and control groups, adjusting for baseline characteristics an ANCOVA test was used.

A stepwise regression analysis was performed to determine factors associated with TIR. TIR served as the dependent variable, and factors such as age, sex, time sensor active, ICR, and BMI were considered independent variables.

Data and Resource Availability:

The datasets generated during and/or analyzed during the current study are not publicly available due to patient confidentiality, but are available from the corresponding author upon reasonable request. The CHOC-BC mobile application used in this study is publicly available for download at <https://apps.apple.com/sa/app/ikfmc/id478245466>

Results

Baseline Characteristics:

A total of 140 participants were enrolled in the study and randomly assigned to either the intervention (n = 70) or control (n = 70) group. Based on the exclusion criteria, 127 participants were included in the final analysis (64 to intervention and 63 to control). Fig. 1 shows a flow diagram illustrating the participant flow throughout the study (including enrollment, randomization, allocation, and analysis).

The study demonstrated successful randomization between intervention and control groups, with no statistically significant differences in age (mean age approximately 26-27 years) or duration of diabetes (around 13 years) between groups. Baseline characteristics were comparable in the two groups, including age, diabetes duration, weight, body mass index (BMI) and Anthropometric measures including weight and BMI were similar between groups (mean BMI approximately 25 kg/m²), indicating comparable baseline characteristics. Importantly, baseline-HbA1c (Table 1) levels were not significantly different between application users and controls (approximately 8.15% [66 mmol/mol] in both groups), ensuring a balanced starting

Commented [RA11]: If you randomise, this is to be expected. I suggest delete.

point for the study. CGM-derived metrics were also similar expect for. The comparison between the intervention and control groups using AGP parameters revealed largely similar baseline metrics. Key measures such as TIR and time spent below 70 mg/dL did not significantly differ between groups ($p > 0.05$), suggesting comparable glycemic profiles at the study outset. Glycemic variability (GV) also showed no significant differences between groups. However, the intervention group did exhibit a higher percentage of time above range (>180 mg/dL) compared to controls (28.52% vs. 25.92%, $p = 0.006$). Data are summarized in Table 1. These findings underscore the balanced baseline characteristics and engagement levels between the intervention and control groups, laying a foundation for evaluating the impact of the CHOC-BC application on glycemic outcomes. Data are summarized in Table 1.

Primary Outcome:

The primary outcome was achieved better in the intervention group compared with the control group. The CHOC-BC application users had significantly better higher TIR (70–180 mg/dL) compared with controls ($51.20\% \pm 11.61\%$ vs. $46.17\% \pm 13.02\%$; mean difference [MD], 5.03; 95% CI, 0.70–9.36; $p < 0.001$) adjusted for age, BMI, preintervention TIR, average sensor capture and application use assignment (Fig. 2A).

Commented [RA12]: Not sure I understand this.

Secondary Outcome:

The CHOC-BC application showed significant benefits in several secondary outcomes. Users of the application spent significantly less time above the high glucose threshold (>250 mg/dL) compared with the control group ($17.25\% \pm 11.61\%$ vs. $24.10\% \pm 15.74\%$; MD, -6.85; 95% CI, -11.70 to -1.99; $p < 0.001$), adjusted for age, BMI, average sensor capture, TIR, preintervention percentage of glucose readings above 250 mg/dl and application use assignment (Fig. 2B). Moreover, GV was significantly improved in the intervention group compared with

Commented [RA13]: Again, not sure I get this.

the control group ($39.83\% \pm 5.50\%$ vs. $41.94\% \pm 5.78\%$, $p < 0.001$, adjusted for age, BMI, average sensor capture, time in range, preintervention percentage of glucose readings above 250 mg/dl and application use assignment (Fig. 2C). Additionally, ~~the~~ mean glucose levels were significantly lower in the intervention group after using the application (179.19 ± 27.92 vs. 191.71 ± 35.78 , respectively; $p < 0.001$), adjusted for age, BMI, and preintervention average sensor capture, time in range, average glucose and application use assignment (Fig. 2D). On the other hand, HbA1c did not differ significantly between the two groups (HbA1c; 63 mmol/mol [$7.93\% \pm 0.85\%$] vs. 66 mmol/mol [$8.15\% \pm 1.02\%$], $p = 0.189$) for intervention and control groups. ~~The time spent between 180 and 250 mg/dL, GMI did not show a significant difference.~~ Data are summarized in Table 2.

Bi-monthly data:

To fully assess the impact of CHOC-BC application on TIR, this metric was studied every two weeks ~~TIR was measured in the intervention group every 2 weeks for safety monitoring. Interestingly, the observed changes in TIR response among users showed a distinct pattern, with~~ The greatest absolute increments in TIR occurred occurring during the first 2 weeks increasing from 46% and again in the last 2 weeks of the study period. At baseline, the TIR was 46%. It then increased to 51.8% in the first 2 weeks with a peak of 52.3% at , representing a 12.5% increase from the baseline. Subsequently, the TIR decreased slightly to 49.5% in week 4. However, it rebounded to 51.1% in week 6 and remained relatively stable at 51.1% and 51.3% in the following 2 weeks. Notably, it increased again in the final 2 weeks, reaching 52.3%, representing a 13.6% increase from the baseline (Supplemental S2).

Safety Outcome:

~~The CHOC-BC application demonstrated good safety outcomes over the study period.~~

Commented [RA14]: As above

Commented [RA15]: As above
Not sure anyone cares about this.

Commented [RA16]: These small fluctuations are completely irrelevant.

The time spent below 70 mg/dL did not differ significantly between the two groups. In addition, the number of low-glucose events did not differ significantly between the intervention and control groups (47.56 ± 36.53 vs. 45.95 ± 27.22 , respectively; $p = 0.779$). Furthermore, despite the application's focus on flexible food choices, weight and BMI results did not differ significantly between groups. Data are summarized in Table 2.

Regression Analysis Model for Time in Range:

A stepwise regression analysis was conducted to identify factors associated with achieving the TIR (70–180 mg/dL) post-intervention. The dependent variable was ~~the~~ TIR. Independent factors included age, sex, percentage of time sensor active, ICR, and BMI. Through the stepwise selection process, only two variables emerged as statistically significant predictors of the target blood glucose range percentage: the percentage of time sensor active and ICR.

Discussion and Conclusion

Diabetes technology, particularly smartphone-based applications like the CHOC-BC introduced in this study, has significantly improved glucose control for individuals with T1DM. In this randomized controlled trial, it was found that application users experienced more than 6% about a 5%-increase in TIR, equating to almost 1.5 hours/day; averaging an additional 70 minutes daily over 3 months. Furthermore, application users showed a reduction of approximately 2 hours per day in level 2 hyperglycemia (>250 mg/dL), along with lower average glucose levels and decreased GV. The safety of the application was ensured, as there were no significant differences in time spent in hypoglycemia between users and controls. This study establishes an important connection between the mobile-based CHOC-BC application and TIR, which is a key measure of glucose control recommended by experts in the field (15).

The CHOC-BC application may enhance glycemic control by improving insulin dose calculations and patient engagement. It offers an effective tools for accurate bolus and correction dose calculations based on carbohydrate intake, ~~and it includes a database of over 700 food items, ranging from traditional dishes to restaurant options.~~ By automating correction dose calculations, the application simplifies a traditionally complex process, potentially improving adherence. Additionally, users have shown a rise in glucose monitoring frequency over time, suggesting greater engagement in self-management. This finding aligns with previous research that links higher scanning rates to improved glucose control (23).

Commented [RA17]: No data are presented on this in the results.

A number of studies have ~~Previous research has~~ examined the relationship between CHOC and glycemic control in adults with T1DM, ~~primarily focusing on HbA1c as the primary endpoint.~~ In a short-term study conducted by Ayano-Takahara et al. in 2015, a positive correlation was found between carbohydrate intake and TIR over 72 hours (24). However, most studies have primarily used HbA1c ~~levels~~ to assess glycemic control. Schmidt et al. and Hommel et al. demonstrated improved glycemic control with CHOC interventions using bolus calculators over 16 weeks and 12 months, respectively (8,18). Notably, the DAFNE study reported significant HbA1c improvements over 6 months for patients with poor glycemic control HbA1c>9% [75 mmol/mol] with the use of CHOC ~~HbA1c~~ (9). ~~However~~ ~~In contrast~~, our study participants had moderately elevated baseline HbA1c levels of 66 mmol/mol [8.15% ± 0.87%]), which may explain the lack of significant improvement in HbA1c ~~observed~~. Additionally, the shorter duration of our study (12 weeks) may have contributed to these non-significant findings, given that as HbA1c improvements can lag behind TIR levels can be quite variable and may be unreliable ~~(25–27).~~

Commented [RA18]: Unclear, what are you trying to say here?

Commented [RA19]: Would only use reference 25

~~The existing literature on HbA1c reduction with carbohydrate counting has yielded~~

mixed results. For example, Laurenzi et al. conducted a 24-week CHOC intervention with 61 adults with T1DM using continuous subcutaneous insulin infusion (CSII). However, they found no significant change in HbA1c levels (28). Additionally, it is important to note that our study

was not specifically designed to evaluate HbA1c changes.

The assessment of the safety of the CHOC-BC application, using CGM technology and ACP data, We showed no significant differences in time spent in hypoglycemia levels between users and non-users of the application. This suggests that the application is a safe tool for individuals with T1DM, potentially enhancing confidence in CHOC and insulin dosing before meals, thus reducing high glucose levels without an increase in possibly reducing the risk of hypoglycemia (29). Previous studies utilizing similar diabetes technologies, such as the ABC device and self-monitoring of blood glucose (SMBG), have reported comparable hypoglycemia outcomes in CHOC interventions, further supporting the safety and efficacy of incorporating such technology into diabetes management (8,18,30).

Our study found a significant improvement in GV in the intervention group, indicating that the CHOC-BC application effectively reduces fluctuations in blood glucose levels. This improvement may be due to more accurate carbohydrate counting and insulin dosing, which the application facilitates. This supports findings from other studies that link accurate carbohydrate counting with reduced GV in individuals with T1DM (31,32).

The strengths of this study include being the first to examine the effect of a mobile-based application that combines carb counting and bolus calculation on TIR, a recognized measure of glucose control. The randomised study design helped to ensure efficacy and safety the data are robust study utilized randomized controlled sampling, which provides robust evidence of

Commented [RA20]: This is a pump study, which is irrelevant.

~~efficacy. Additionally, the use of CGMS enabled close patient monitoring and extensive glucose data collection, ensuring application safety and effectiveness.~~

The study has several limitations. Firstly, the control group had a higher baseline time spent in the glucose range of 180–250 mg/dL. ~~This issue can occur in clinical trials, even with successful randomization, as indicated by the other parameters. However, this was corrected for in our analysis.~~ Secondly, the intervention group was monitored every 2 weeks, which may have influenced glycemic outcomes; however, this frequent monitoring was necessary to collect the data and to ensure the safety of the newly-introduced application ~~especially it is a newly introduced technology.~~ Third~~ly~~~~Additionally~~, compliance with the application was not directly measured, ~~and the technology used needed further enhancement of the current version.~~ Fourth~~ly~~, there were inaccuracies in the carbohydrate content of some traditional meals, which was noted after the study ended but they were detected in a minority of meals and unlikely to have affected study findings ~~highlighting areas that need improvement in future studies.~~ Finally, the application was tested in a single centre and therefore more work is needed to ensure generalisability of the results to other centres and patient populations.

In summary, using technology to enhance CHOC is a rapidly advancing field that has the potential to improve the management of T1DM. The introduction of the mobile-based CHOC-BC application has shown promising results in this pilot study, demonstrating improved glucose control among individuals with T1DM, without increasing the risk of hypoglycemia or weight gain. ~~Based on the findings of this randomized controlled trial (RCT), it is recommended that patients with T1DM utilize such applications to improve CHOC and bolus calculations.~~

~~Clinical dietitians should be encouraged to learn and promote this technology to maximize its benefits for patients.~~ Future studies should explore the application's usefulness

across a broader range of patients with T1DM, including pediatric, adolescent, and pregnant populations. Additionally, further research is necessary to evaluate the application's impact on long-term diabetes complications and to expand its capabilities, potentially incorporating artificial intelligence technologies for automated carbohydrate estimation via a mobile camera.

Acknowledgment

The authors would like to thank the Research Centre at King Fahad Medical City, Riyadh, for their valuable financial support provided for the manuscript (RFA 023-015).

Conflict of Interest:

The authors declare no conflict of interest

Author Contributions:

S.A. was involved in the conception, design, and conduct of the study and in researching data. T.A. researched data. S.A. and S.H.A. wrote the first draft of the manuscript. A.J., M.A., and R.A. reviewed and edited the manuscript. T.W. conducted the statistical analysis. S.H.A. and N.A. contributed to the discussion and reviewed and edited the manuscript. All authors reviewed and approved the final version of the manuscript.

Guarantor Statement:

S.A. is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Prior Presentation:

Parts of this study were presented at the 84th Scientific Sessions of the American Diabetes Association, held on 21–24 June 2024 in Orlando, Florida, and published as an abstract in *Diabetes* 2024; 73(Suppl. 1): 622-P. [<https://doi.org/10.2337/db24-622-P>].

References

1. Brison DW. Definition, diagnosis, and classification. Ameliorating Mental Disability: Questioning Retardation. 2017. p. 1–19.
2. Green A, Hede SM, Patterson CC, Wild SH, Imperatore G, Roglic G, et al. Type 1 diabetes in 2017: global estimates of incident and prevalent cases in children and adults. *Abbreviations CM Child mortality rate EURODIAB Europe and Diabetes GBD Global Burden of Disease HIC High-income country LIC Low-income country. Diabetologia.* 2021;64(12):2741–50.
3. Vaz EC, Porfírio GJM, Nunes HR de C, Nunes-Nogueira VDS. Effectiveness and safety of carbohydrate counting in the management of adult patients with type 1 diabetes mellitus: A systematic review and meta-analysis. *Arch Endocrinol Metab.* 2018;62(3):337–45.
4. Donzeau A, Bonnemaïson E, Vautier V, Menut V, Houdon L, Bendelac N, et al. Effects of advanced carbohydrate counting on glucose control and quality of life in children with type 1 diabetes. *Pediatr Diabetes.* 2020;21(7):1240–8.
5. Builes-Montaña CE, Ortiz-Cano NA, Ramirez-Rincón A, Rojas-Henao NA. Efficacy and safety of carbohydrate counting versus other forms of dietary advice in patients with type 1 diabetes mellitus: a systematic review and meta-analysis of randomised clinical trials. *J Hum Nutr Diet.* 2022 Dec;35(6):1030–42.
6. Fu S et al. Effectiveness of advanced carbohydrate counting in type 1 diabetes mellitus: a systematic review and meta-analysis. *Sci Rep.* 2016 Nov;6(1):37067.
7. Jenkins D, Wolever T, Rao A V., Hegele RA, Mitchell SJ, Ransom T, et al. The New England Journal of Medicine Downloaded from nejm.org on March 29, 2011. For

personal use only. No other uses without permission. N Engl J Med. 1993;329(1):21–6.

8. Schmidt S, Meldgaard M, Serifovski N, Storm C, Christensen TM, Gade-Rasmussen B, et al. Use of an automated bolus calculator in MDI-treated type 1 diabetes: The BolusCal study, a randomized controlled pilot study. Diabetes Care. 2012;35(5):984–90.
9. Amiel S, Beveridge S, Bradley C, Gianfrancesco C, Heller S, James P, et al. Training in flexible, intensive insulin management to enable dietary freedom in people with type 1 diabetes: Dose adjustment for normal eating (DAFNE) randomised controlled trial. Br Med J. 2002;325(7367):746–9.
10. Davison KAK, Negrato CA, Cobas R, Matheus A, Tannus L, Palma CS, et al. Relationship between adherence to diet, glycemic control and cardiovascular risk factors in patients with type 1 diabetes: a nationwide survey in Brazil. Nutr J [Internet]. 2014 Dec 7;13(1):19. Available from: <http://nutritionj.biomedcentral.com/articles/10.1186/1475-2891-13-19>
11. Lancaster BM, Pfeffer B, Mcelligott M, Ferguson AT, Miller M, Wallace D, et al. Assessing treatment barriers in young adults with type 1 diabetes. Diabetes Res Clin Pract. 2010;90(3):243–9.
12. Meade LT, Rushton WE. Accuracy of carbohydrate counting in adults. Clin Diabetes. 2016;34(3):142–7.
13. Anthimopoulos M, Dehais J, Shevchik S, Ransford BH, Duke D, Diem P, et al. Computer vision-based carbohydrate estimation for type 1 patients with diabetes using smartphones. J Diabetes Sci Technol. 2015;9(3):507–15.
14. Fakih El Khoury C, Karavetian M, Halfens RJG, Crutzen R, Khoja L, Schols JMGA. The Effects of Dietary Mobile Apps on Nutritional Outcomes in Adults with Chronic Diseases:

A Systematic Review and Meta-Analysis. *J Acad Nutr Diet*. 2019;119(4):626–51.

15. Battelino T, Danne T, Bergenstal RM, Amiel SA, Beck R, Biester T, et al. Clinical targets for continuous glucose monitoring data interpretation: Recommendations from the international consensus on time in range. *Diabetes Care*. 2019;42(8):1593–603.
16. AlBabtain SA, AlAfif NO, AlDisi D, AlZahrani SH. Manual and Application-Based Carbohydrate Counting and Glycemic Control in Type 1 Diabetes Subjects: A Narrative Review. *Healthcare*. 2023 Mar;11(7):934.
17. Fortin A'anne, Desjardins K, Brazeau A, Ladouceur M. Practices , perceptions and expectations for carbohydrate counting in patients with type 1 diabetes – Results from an online survey. *Diabetes Res Clin Pract*. 2017;6:0–7.
18. Hommel E, Schmidt S, Vistisen D, Neergaard K, Gribhild M, Almdal T, et al. Effects of advanced carbohydrate counting guided by an automated bolus calculator in Type 1 diabetes mellitus (StenoABC): a 12-month, randomized clinical trial. *Diabet Med*. 2017;34(5):708–15.
19. Chow S-C, Wang H, Shao J. Sample Size Calculations in Clinical Research. *Sample Size Calculations in Clinical Research*. 2007.
20. Julious SA. Sample sizes for clinical trials with Normal data. *Stat Med [Internet]*. 2004 Jun 30;23(12):1921–86. Available from: <https://onlinelibrary.wiley.com/doi/10.1002/sim.1783>
21. Lovely et al. Applied carbohydrate counting. *J Pak Med Assoc*. 2017;67(9):1456–7.
22. Wheeler ML, Daly A, Evert A, Franz MJ, Geil P, Holzmeister LA, et al. Choose Your Foods: Exchange Lists for Diabetes, Sixth Edition, 2008: Description and Guidelines for Use. *J Am Diet Assoc*. 2008;108(5):883–8.

23. Sebastian-Valles F, Martínez-Alfonso J, Arranz Martin JA, Jiménez-Díaz J, Hernando Alday I, Navas-Moreno V, et al. Scans per day as predictors of optimal glycemic control in people with type 1 diabetes mellitus using flash glucose monitoring: what number of scans per day should raise a red flag? *Acta Diabetol* [Internet]. 2023 Nov 6;61(3):343–50. Available from: <https://link.springer.com/10.1007/s00592-023-02204-x>
24. Ayano-Takahara S, Ikeda K, Fujimoto S, Asai K, Oguri Y, Harashima S, et al. Carbohydrate intake is associated with time spent in the euglycemic range in patients with type 1 diabetes. *J Diabetes Investig*. 2015 Nov;6(6):678–86.
25. Beck RW, Connor CG, Mullen DM, Wesley DM, Bergenstal RM. The fallacy of average: How using hba1c alone to assess glycemic control can be misleading. *Diabetes Care*. 2017;40(8):994–9.
26. Cohen RM, Franco RS, Khera PK, Smith EP, Lindsell CJ, Ciraolo PJ, et al. Red cell life span heterogeneity in hematologically normal people is sufficient to alter HbA1c. *Blood*. 2008;112(10):4284–91.
27. Lundholm MD, Emanuele MA, Ashraf A, Nadeem S. Applications and pitfalls of hemoglobin A1C and alternative methods of glycemic monitoring. Vol. 34, *Journal of Diabetes and its Complications*. 2020.
28. Laurenzi A, Bolla AM, Panigoni G, Doria V, Uccellatore A, Peretti E, et al. Effects of Carbohydrate Counting on Glucose Control and Quality of Life Over 24 Weeks in Adult Patients With Type 1 Diabetes on Continuous Subcutaneous Insulin Infusion. *Diabetes Care* [Internet]. 2011 Apr 1;34(4):823–7. Available from: <https://diabetesjournals.org/care/article/34/4/823/38815/Effects-of-Carbohydrate-Counting-on-Glucose>

29. Rhyner D, Loher H, Dehais J, Anthimopoulos M, Shevchik S, Botwey RH, et al. Carbohydrate estimation by a mobile phone-based system versus self-estimations of individuals with type 1 diabetes mellitus: A comparative study. *J Med Internet Res.* 2016;18(5):1–12.
30. Scavone G, Manto A, Pitocco D, Gagliardi L, Caputo S, Mancini L, et al. Effect of carbohydrate counting and medical nutritional therapy on glycaemic control in Type 1 diabetic subjects: A pilot study. *Diabet Med.* 2010;27(4):477–9.
31. Brazeau AS, Mircescu H, Desjardins K, Leroux C, Strychar I, Ekoé JM, et al. Carbohydrate counting accuracy and blood glucose variability in adults with type 1 diabetes. *Diabetes Res Clin Pract.* 2013 Jan;99(1):19–23.
32. Alzahrani B, Alzahrani S, Almalki MH, Elabd SS, Khan SA, Buhary B, et al. Glycemic Variability in Type 1 Diabetes Mellitus Saudis Using Ambulatory Glucose Profile. *Clin Med Insights Endocrinol Diabetes.* 2021 Jan;14:117955142110137.

Commented [RA21]: Check all references as some contain irrelevant info (such as reference 7), while others are missing info such as page numbers.

Tables:

Variable	Intervention	Control	<i>p</i> -value
	mean ± SD	mean ± SD	
	n = 64	n = 63	
Age	26.56 ± 4.8	26.74 ± 6.52	0.854
Sex (males, %)	39.1	54	0.090
Duration of DM (years)	13.38 ± 7.58	13.51 ± 6.34	0.915
Weight (kg)	67.38 ± 15.55	68.46 ± 14.02	0.681
Body Mass Index (kg/m ²)	24.7 ± 4.64	25.38 ± 4.5	0.409
HbA1c (%)	8.15 ± 0.87	8.16 ± 0.96	0.974
HbA1c (mmol/l)	56 - 75		
LDL (mmol/L)	2.91 ± 0.8	2.93 ± 0.81	0.840
Total cholesterol (mmol/L)	4.51 ± 0.88	4.37 ± 0.84	0.369
Triglyceride (mmol/L)	0.81 ± 0.35	0.86 ± 0.36	0.449
Time in range (%)	46.03 ± 10.93	44.79 ± 11.99	0.544
Time spent above 180 mg/dL (%)	28.52 ± 5.48	25.92 ± 5.01	0.006*
Time spent above 250 mg/dL (%)	21.47 ± 11.90	24.98 ± 13.42	0.121
Time spent below 70 mg/dL (%)	3.33 ± 2.85	3.70 ± 2.28	0.421
Time spent below 54 mg/dL (%)	0.66 ± 1.26	0.60 ± 0.94	0.789
Glucose variability (%)	39.76 ± 5.48	41.41 ± 5.42	0.100
GMI (%)	7.83 ± 0.67	7.94 ± 0.73	0.376
Average glucose (mg/dL)	189.52 ± 28.09	193.83 ± 30.43	0.408
Low-glucose events	42.38 ± 30.26	43.94 ± 24.69	0.751

Table 1: Baseline anthropometric, laboratory and flash glucose monitoring data

SD: standard deviation, DM: diabetes mellitus, BMI: body mass index, HbA1c: hemoglobin A1c,

LDL: low-density lipoprotein, * *P*-value < 0.005

Variable	Intervention	Control	p-value
	mean $\pm$ SD	mean $\pm$ SD	
	n = 64	n = 63	
Weight (kg)	67.31 $\pm$ 15.12	68.67 $\pm$ 14.32	0.606
Body mass index (kg/m ²)	24.36 $\pm$ 5.39	25.47 $\pm$ 4.57	0.215
HbA1c (%)	7.93 $\pm$ 0.85	8.15 $\pm$ 1.02	0.189
HbA1c (mmol/l)	54 - 72	54 - 77	
LDL (mmol/L)	2.84 $\pm$ 0.72	2.83 $\pm$ 0.75	0.985
Total cholesterol (mmol/L)	44.4 $\pm$ 0.79	4.33 $\pm$ 0.94	0.506
Triglyceride (mmol/L)	0.74 $\pm$ 0.32	0.85 $\pm$ 0.42	0.109
Time in range (%)	51.20 $\pm$ 11.61	46.17 $\pm$ 13.02	<0.001*†
Time spent above 180 mg/dL (%)	27.02 $\pm$ 5.19	25.43 $\pm$ 5.45	0.095
Time spent above 250 mg/dL (%)	17.25 $\pm$ 11.61	24.10 $\pm$ 15.74	<0.001*†
Time spent below 70 mg/dL (%)	3.58 $\pm$ 3.0	3.84 $\pm$ 2.4	0.586
Time spent below 54 mg/dL (%)	0.69 $\pm$ 0.97	0.75 $\pm$ 1.05	0.745
Glucose variability (%)	39.83 $\pm$ 5.50	41.94 $\pm$ 5.78	<0.001*†
GMI (%)	7.60 $\pm$ 0.67	7.8 $\pm$ 1.16	0.225
Average glucose (mg/dL)	179.19 $\pm$ 27.92	191.71 $\pm$ 35.78	<0.001*†
Low-glucose events	47.56 $\pm$ 36.53	45.95 $\pm$ 27.22	0.779

Table 2: Final glucose metrics, laboratory and anthropometrics in intervention and control arms.

*A p-value of <0.05 was considered to indicate statistical significance. SD: standard deviation, GMI: Glucose Management Indicator, HbA1c: hemoglobin A1c. † representing p-value after

adjustment with ANCOVA.

Figure Legends:

Figure 1: Flowchart of participant enrollment, allocation, follow-up, and analysis

Figure 2A: Comparison of the percentage of time in range (70–180 mg/dL) post-intervention between the two groups. Data presented after ANCOVA adjustment for age and BMI and preintervention time in range, average sensor capture and application use assignment.

Figure 2B: Comparison of the percentage of time above range (>250 mg/dL) post-intervention between the two groups. The estimates are from ANCOVA model adjusting for age, BMI, average sensor capture, time in range, percentage of glucose readings above 250 mg/dL pre intervention and application use assignment.

Figure 2C: Comparison of the percentage of glucose variability post-intervention between the two groups. The estimates are from ANCOVA model adjusting for age, BMI, average sensor capture, time in range, coefficient of variation all pre intervention and application use assignment.

Figure 12D: Comparison of the percentage of the average glucose level post-intervention between the two groups. The estimates are from ANCOVA model adjusting for age, BMI, average sensor capture, time in range, average glucose all pre intervention and application use assignment.