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Adherence to the Mediterranean diet and sleep quality are inter-correlated with flash glucose monitoring (FGM)-measured glycemia among children with type 1 diabetes

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Abstract:

BACKGROUND: We examined the inter-correlation between diet quality, objectively measured sleep duration, and subjectively measured sleep quality with flash glucose monitoring (FGM)-measured glycemia among young patients with type 1 diabetes (T1D).

MATERIALS AND METHODS: Following cross-sectional design, Fitbit® accelerometers were used to objectively assess sleep duration, while the validated questionnaires Pittsburgh sleep quality index and Mediterranean diet (MD) adherence were used to subjectively assess sleep quality and diet quality, respectively. Glycated hemoglobin (HbA1c) and FGM-reported glycemia components among children with T1D were assessed as well.

RESULTS: Of the 47 participants surveyed (25 boys, 22 girls, 9.31 ± 2.88 years), the majority reported high HbA1c, good sleep quality, and high adherence to the MD. However, only one-third of the participants reported a healthy sleep duration. Only the sleep latency was significantly ($P < 0.05$) associated with the time above range level 2 and time below range level 2 ($P = 0.048$) components of the FGM. A positive correlation ($r = 0.309$, $P = 0.035$) was reported between adherence to MD and time in range of the FGM.

CONCLUSIONS: Diet quality and sleep quality are variably inter-correlated with FGM-measured glycemia among young patients with T1D and are suggested to be considered influential factors in FGM-monitored diabetes research on this age group.

Keywords:

Diabetes mellitus, glycemic control, healthy lifestyle, Mediterranean diet, sleep quality

Introduction

Diabetes is still one of the leading causes of mortality and disability worldwide.[1] Diet and lifestyle, including sleep patterns, are important factors in the management of patients with diabetes.[2] The individualized educational program meets the educational needs of children

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and adolescents with type 1 diabetes (T1D) and their expectations[3] for proper self-management will lead to better blood glucose and time in ranges and reduced morbidity and mortality in adolescents with T1D.[4] The treatment choices are insulin pump therapy or multiple daily injections, with adjustment of insulin dose based on glycemic level, macronutrient (carbohydrate counting) content of the meals, and purposefully planned physical activity.[5] Sleep plays a considerable role in glycemic control, with decreased sleep quality and duration being a negative influence on glycemic control among patients with diabetes.[6]

The Mediterranean diet (MD) is rich in polyunsaturated fatty acids, monounsaturated fatty acids, vitamins, dietary fibers, and pro- and pre-biotics, with a plethora of bioactive antioxidants, anti-inflammatory phytochemicals, and low-glycemic-index foods, a unique mixture that plays a role in a healthier impact on the lipid profile and lowering cardiovascular disease associated with the Western diet, T2D, metabolic syndrome, and obesity associated with the systemic, low-grade inflammatory state.[7]

The favorable effects of combining flash glucose monitoring (FGM) technology into diabetes management include improved glycemic variability, reduced time spent in hypoglycemia,[8] reduced HbA1c levels,[9] and increased numbers of readings per day for the maximum daily care of blood glucose[10] in patients with T1D.[11] Glycemic control among young patients with T1D is usually compromised by an unhealthy diet, disturbance in sleep quality, and widespread use of electronic devices.[12] Determining the relationship between sleep pattern and quality and dietary pattern with FGM-measured glycemic control among children with T1D is of pivotal significance in developing proper intervention strategies and preventative measures to delay diabetic complications and lower the prevalence rate. Therefore, the current work was designed to examine the relationship between CGM-measured glycemia, sleep, and adherence to MD among young patients with T1D in the UAE. The novelty of the current work stems from the fact that it is the first study conducted in the Gulf Cooperation Council (GCC) countries, including the UAE, among young patients with T1D using the CGM and objectively measured sleep duration. Because the majority of relevant studies were performed in Western countries with different genetic, environmental, and socio-economic backgrounds, it becomes crucial to examine the above relationships in the context of GCC countries. The conceptual framework of the current study is based on the hypothesis that CGM-measured glycemia measurement could be affected by the different dietary and lifestyle behaviors (including sleep duration) that may interfere with the glycemic readings.

Materials and Methods

Study design and setting

A cross-sectional study was conducted among children (4–18 years) from the Diabetes and Endocrine Clinic at Al Qassimi Women's and Children's Hospital and the University Hospital Sharjah (UHS) to achieve the study's objectives. Data collection was carried out between December 2021 and January 2022 using convenience sampling. The patients' parents were contacted by phone and invited to participate in the study.

Study participants and sampling

The inclusion criteria for participants were as follows: (1) an age from 4 to <18 years, (2) a diagnosis of T1D (based on the American Diabetes Association diagnosis criteria),[13] (3) patients who were using the FGM, and (4) consent to join the study. The exclusion criteria for participants were as follows: (1) patients with T2D, (2) children with mental disorders and cognitive disabilities, (3) children with a physical disability, and (4) those who could speak neither English nor Arabic.

Before starting the data collection process, the contact information of all the patients that matched the inclusion criteria at the two hospitals was acquired. The participants' parents were then contacted to confirm that the participants had and were wearing a previously provided FGM device. The participants' parents were then presented with a brief introduction about the study, its objectives, and procedures. They were asked to provide signed informed consent if they agreed to participate. Participants were informed that their participation was anonymous and completely voluntary, and no monetary or non-monetary incentives were given to the study's participants. They were free to withdraw from the study at any time or stage, without giving any reasons and without prejudice against their rights as patients.

Data collection tools and technique

Socio-demographic and clinical data

The first socio-demographic questionnaire was an online Google Forms-based survey filled by an interview. The first part of the questionnaire contained questions about the child's personal information. The questions were about age, sex, and body mass index (BMI) using percentile growth chart classifications,[14] current educational level, and nationality. The second part of the questionnaire was about the participants' parental information. All the questions were asked twice, once for each parent. The questions were about the age range, highest educational degree acquired, employment status, and family's current living situation.

Biochemical data

The child's most recent HbA1c within the past 3 months was obtained from the medical records of the participants who had done the test, and for those who had not, a test was performed during the clinic appointment; the continuous variables were categorized: HbA1c percentile <7% considered normal or controlled and ≥7% considered abnormal or uncontrolled.[15]

Assessing dietary habits using KIDMED

The Mediterranean Diet Quality Index (KIDMED) questionnaire was used to assess the degree of adherence to MD; it is the most widely used tool to assess adherence to MD among children and adolescents.[16] The questionnaire was filled out by an interviewer in the English language, and the reliability of this questionnaire was established among college students, r = 0.60.[17] This index, first developed by Serra-Majem *et al*.,[18] addressed food habits specific to the Mediterranean region. A KIDMED score of 8–12 is good, 4–7 is average, and 0–3 is poor, and then KIDMED (adherence to the MD) variables are recategorized to high adherence (score 4–12) and low adherence (score 0–3).

Assessing sleep quality using PSQI

The third questionnaire addressed the sleep quality among study participants using the Pittsburgh Sleep Quality Index (PSQI).[19] The questionnaire was filled out by an interviewer, and the Arabic version of the questionnaire was used as well, which was earlier investigated for its validity and reliability and was found to be appropriate for use among Arabic-speaking natives.[20] Using total PSQI, scores ≤5 scores were considered good, and scores >5 were considered poor sleep quality. The seven components results of the PSQI questionnaire were categorized into good and bad in regression analysis.

Assessing sleep using an accelerometer

Participants wore the accelerometer (Fitbit Ace 2 & 3 for kids) on a band around the wrist to objectively collect and evaluate the participants' sleep data. The Fitbit Ace 2 & 3 tracker can track the number of sleep durations, which can also be added to the Fitbit application on the smartphone connected to the tracker. The initial setup of the Fitbit Ace 2 & 3 requires a parent's Fitbit account. The Fitbit application was downloaded and set up on the participants' parents' mobile phones during the clinic appointment. The child was then added to the Fitbit application. Tutorials and demonstration videos about the Fitbit Ace 2 & 3 activity tracker for future follow-ups and result collection were sent via the "WhatsApp" application. The participants were asked to wear the Fitbit tracker 24 hours for 7 consecutive days and nights based on previous recommendations.[21] After 7 days, the participant's parents were asked to send screenshots from the Fitbit application connected to the activity tracker, showing all the requested information and results. The screenshots of the results were then used to input and analyze the data manually.

The Fitbit sleep duration was converted to hours by dividing the measured number of minutes by 60. Then it was categorized as good (≥9–12 h for 4–12 years old and ≥8–10 h for 13–18 years old children) per day and bad (<9 h for 4–12 years old children and <8 h for 13–18 years old child) per day.[22]

Assessing glycemic control and glycemic variability using FGM:

All participants (n = 47) included in the study had been using the "FreeStyle™ Libre" Abbott sensor. The device usually contains two parts: a sensor kit inserted subcutaneously and changed every 14 days and a reader device to scan for the readings (at least 3 times a day) to ensure the accuracy of the data. Some patients use the mobile application and scan the sensor with their mobile phones instead of the reader device. Patients had linked their glucose data to our hospital database using the LibreView online platform (libreview.com). Of the patients with diabetes who are LibreView users, we identified a cohort of 36 patients with glucose profile data uploaded within 14 days before the study recruitment day. We excluded patients with a low sensor data capture (11 patients) following the recommendation of the International Consensus on the Use of Continuous Glucose Monitoring.[23] Assessment of different FGM parameters was calculated using the CGM analysis package of the R-studio software.[24] Evaluation of the CGM components was carried out according to Battelino *et al*.[25] Assessment of different FGM parameters was calculated using the CGM analysis package of the R-studio software.[24] These variables include mean average glucose (MAG), glucose management indicator (GMI), estimated A1c, inter-quartile ranges of glucose, coefficient of variation (CV), time spent in range (TIR) (70–180 mg/dL, 3.9-10.0 mmol/L), time spent in hypoglycemia (TBR) level 1 (54–70 mg/dL, 3.9–3.0 mmol/L), time spent in hypoglycemia (TBR) level 2 (<54 mg/dL, <3.0 mmol/L), time spent in hyperglycemia (TAR) level 1 (180–250 mg/dL, 10.0–13.9 mmol/L), time spent in hyperglycemia (TAR) level 2 (>250 mg/dL, >13.9 mmol/L), mean amplitude of glycemic excursions (MAGE), mean of daily differences (MODD), low blood glucose index (LBGI), high blood glucose index (HBGI), and area under the curve (AUC).[23,25]

Ethical considerations

The protocol of this study was designed and executed following the Declaration of Helsinki for medical research ethics. The survey's protocol and data collection instruments were reviewed and approved by the Research

Ethics Committee at the University of Sharjah Hospital (UHS-HERC-073-16092021) and the Ministry of Health and Prevention (MOHAP/DXB-REC/SOO/No. 88/2021).

Statistical analysis

Participants' response data were encoded and analyzed using the Statistical Package for Social Sciences (SPSS), version 26.0. The continuous socio-demographic data were presented as mean and standard deviations (SD) like weight, height, and age. The categorical variables were described using frequencies and percentages of observed values.

The correlation test was done to assess the correlation between every two continuous variables. Then, the strength of the correlation was described as follows: 0–0.19 is regarded as very weak, 0.2–0.39 as weak, 0.40–0.59 as moderate, 0.6–0.79 as strong, and 0.8–1 as very strong correlation. The cross-tabulation function was used to distribute participants on 2 X 2 variables; the odds ratio (OR), 95% confidence intervals (CIs), and the Chi-square *P* value were used to assess the associations between categorical variables. The significance level of all data was set at a $P < 0.05$. Valid FGM blood glucose data with adequate sensor data capture were included (n = 36). Median (IQR) blood glucose values for the 36 participants in the appointed 14 days were plotted in 24-hour distribution using the cgmanalysis package in R-studio software.[24] Data tests for normality, descriptive analysis, and Student's *t*-test were carried out on GraphPad Prism software (Version 9.2.0, San Diego, California, USA www.graphpad.com) for macOS.

Results

Of the 47 participants, more than half were males. The participants had a mean age of 9.31 years, with more than half of them being in the age range between 8 and 12 years. Vast majority of the participants' BMI were within the normal range, with the rest being within the obese category. Children in the secondary school were the highest proportion (44.7%). More than half of the study participants were Arab Gulf Cooperation Council (GCC) residents [Table 1]. Sociodemographics of children's parents are shown in Supplementary Table 1. The vast majority of the parenst earned bachelor's degree, most of their fathers were emplyed and working for less than 9 hours/day, while the majorty of mothers were not employed.

The vast majority of the recruited children had uncontolled diabetes with HbA1c% of ≥7, reported good sleep quality (Global PSQI ≤5), expressed bad Fitbit sleep duration average expressed in terms of sleep hours/day, and reporetd high adherence levels to the MD as presnted in terms of KIDMED adherence score of 4-12 [Table 2]. Flash glucose monitoring (FGM) descriptive data analysis is detailed in Table 3.

Table 1: Descriptive data of study population (children T1D, *n*=47) (categorical variables and continuous variables)

Variable	Category	*n* (%)
Categorical variables		
Sex	Male	25 (53.2%)
	Female	22 (46.8%)
Age (Years)	4-7	15 (31.9%)
	8-12	25 (53.2%)
	13-18	7 (14.9%)
BMI (kg/m^2) percentile	≥5% and <85%	34 (72.3%)
	≥85% and <95%	5 (10.6%)
	≥95%	8 (17.0%)
Educational level	Kinder garden	6 (12.8%)
	Primary school (Grade 1-Grade 4)	18 (38.3%)
	Secondary school (Grade 5-Grade 9)	21 (44.7%)
	High school (Grade 10-Grade 12)	2 (4.3%)
Nationality	Arab GCC	27 (57.4%)
	Arab Non-GCC	19 (40.4%)
	Non-Arab	1 (2.1%)
Living status	Parents living together	44 (93.6%)
	Parents divorced/separated	3 (6.4%)
Continuous variables (mean±SD)		
Age (Years)	9.31±2.88	Minimum=4.0
		Maximum=15.0
Weight (kg)	36.42±13.99	Minimum=16.40
		Maximum=65.0
Height (cm)	136.92±15.97	Minimum=107.0
		Maximum=179.0

*BMI classifications: (≥5% and <85% normal weight, ≥85% and <95% overweight, ≥95% obese)

The very high glucose level had a positive correlation with the HbA1c percentile of the last 3 months and a stronger negative correlation with the TIR (r = -0.918, $P < 0.001$) [Supplementary Table 2]. The HbA1c also showed a negative correlation with the TIR. In addition, the data showed a medium positive correlation between sleep duration PSQI and TIR with KIDMED, with correlation values of ($r = 0.296$, $P < 0.043$) and ($r = 0.309$, $P < 0.035$), respectively. Other positive correlations were shown between time below range (TBR) levels 1 and 2 with the glucose variability, with correlation values of ($r = 0.609$, $P < 0.001$) and ($r = 0.613$, $P < 0.001$), respectively [Supplementary Table 2].

There was no association between the scale of the dietary behavior (adherence to the MD diet), with HbA1c, and the TIR parameters among children's patients with T1D [Supplementary Table 3].

The global PSQI score (categorical variables 2 X 2) was associated neither with HbA1c% ($P = 0.630$, OR = 0.794, 95% CI; 0.074–8.576) nor with TIR parameters using cut-off points, where ≤5 scores were considered good and

>5 was considered poor sleep quality [Supplementary Table 4]. The seven components of the PSQI questionnaire were categorized into good (0–1) and bad (2–3) to be used in regression analysis. The sleep efficiency and sleep medications components were removed from the table because no participants distributed in the "bad" category were present, whereas the remaining five individual components of the PSQI were examined concerning the HbA1c% and AGP parameters to explore how specific components of sleep were related to diabetes control.

Table 2: Tested HbA1cand subjectively measured sleep quality and adherence to the Mediterranean diet, for the study participants

Variable	Category	*n* (%)
HbA1c (%)	<7 normal (controlled)	10 (21.3%)
	≥7 abnormal (uncontrolled)	37 (78.7%)
Total PSQI score	Good sleep quality ≤5	43 (91.5%)
	Poor sleep quality >5	4 (8.5%)
Fitbit sleep duration average (hour/day)	Good	16 (34.0%)
	4-12 years (≥9-12)	
	13-18 years (≥8-10)	
	Bad	31 (66.0%)
	4-12 years (<9)	
	13-18 years (<8)	
KIDMED adherence score	High adherence (4-12)	35 (74.5%)
	Low adherence (0-3)	12 (25.5%)

*HbA1c%: <7% (controlled), ≥7 (uncontrolled). *PSQI: Pittsburgh Sleep Quality Index (Good sleep quality ≤5), Poor sleep quality >5. *KIDMED: Mediterranean Diet Quality Index for children and teenagers and poor adherence (≤3), average adherence (between 4 and 7), and good adherence (≥8) variables are recategorized to high adherence (score 4-12) and low adherence (score 0-3)

Table 3: Flash glucose monitoring (FGM) descriptive data analysis

FGM Metrics (*n*=36)	Descriptive analysis
*MAG (mg/dL), median (IQR)	170.8 (156-225.4)
GMI (mmol/L), Median (IQR)	7.4 (7-8.7)
Estimated HbA1c, Median (IQR)	7.55 (7.1-9.48)
CV, Mean (SD)	40.66 (6.98)
Percentage of TIR, Mean (SD)	48.52 (19.17)
Percentage of TBR level 1, median (IQR)	2.72 (1.71-4.18)
Percentage of TBR Level 2, median (IQR)	0.4 (0.18-0.96)
Percentage of TAR level 1, mean (SD)	23.1 (6.6)
Percentage of TAR level 2, median (IQR)	14.2 (8.18-39.03)
Total AUC, median (IQR)	3634084 (3084902-4359611)
MAGE, Mean (SD)	159.8 (46.13)
MODD, Mean (SD)	77.05 (25.08)
LBGI, median (IQR)	3.94 (3.15-4.944)
HBGI, median (IQR)	13.84 (9.61-23,09)
CONGA, Mean (SD)	60.44 (16.1)
J-Index, median (IQR)	59.64 (45.64-105.2)

Data presented as mean (SD) or median (IQR) as stated. *MAG: mean average glucose (mean sensor), GMI: glucose management indicator, CV: coefficient of variation, TIR: time in range (defined as 70-180 mg/dL), TBR: time below range (level 1: 54-70 mg/dL; level 2: <54 mg/dL), TAR: time above range (level 1: 180-250 mg/dL; level 2: >250 mg/dL), AUC: area under the curve, MAGE: mean amplitude of glycemic excursions, MODD: mean of daily differences, LBGI: low blood glucose index, HBGI: high blood glucose index. CONGA: continuous overall net glycemic action

Of the seven PSQI components, only the sleep latency sub-scale was significantly associated with high TIR and very low TIR components with *P* values of 0.02 and 0.048, respectively. The OR (95% CI) values of the sleep latency in association with the high TIR were 0.318 (0.031–3.306). Almost a third of the participants had a good sleep latency and an acceptable TAR level 1 percentage value, whereas a very small percentage of participants had a bad sleep latency associated with an unacceptable TAR level 1 percentage value [Supplementary Table 4].

More than half of the study participants had a good sleep latency with an acceptable TBR level 2 percentage value, whereas the lowest percentage of participants (8.5%) had a bad sleep latency with an acceptable TBR level 2 percentage value. All the remaining variables and sleep components (sleep quality, sleep duration, sleep disturbances, sleep dysfunction) showed no association with the FGM glucose control parameters.

Figure 1 uses Tukey's running median smoothing after rounding each time point to the nearest 10-minute mark to demonstrate the blood glucose level of the participants (n = 36) through the examined days and shows the 24-hour distribution for more visuality of the intra-day and night changes. The plot shows the glucose range, denoting median, 5th, 25th, 75th, and 90th percentiles.

The median blood glucose was between 150 and 200 mg/dl in most of the daytime with consistent evening and midnight elevation. The 24-hour curve validates the high glucose variability consistent with a high CV percentage as previously mentioned in Table 3.

The percentages of TIR, TAR (hyperglycemia levels 1 and 2), and TBR (hypoglycemia levels 1 and 2) for the participants in 14 days are depicted in Figure 2. The

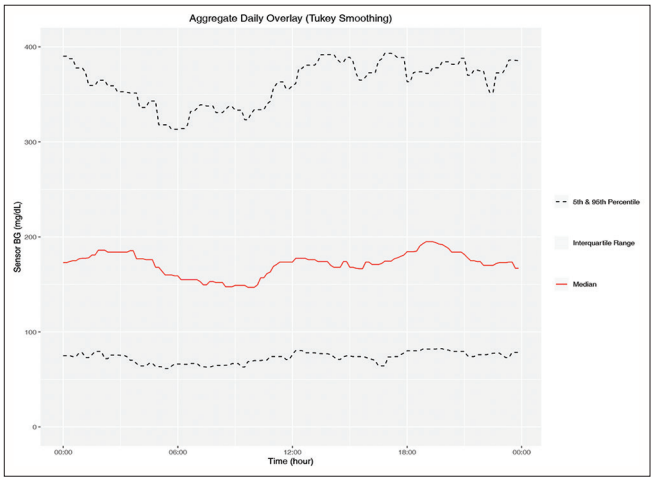

Figure 1: FGM glucose profile (n=36) in 14 days. The red line indicates median glucose and the purple shaded area shows the 25th and 75th percentiles. Black dotted lines denote the 5th and 95th percentiles

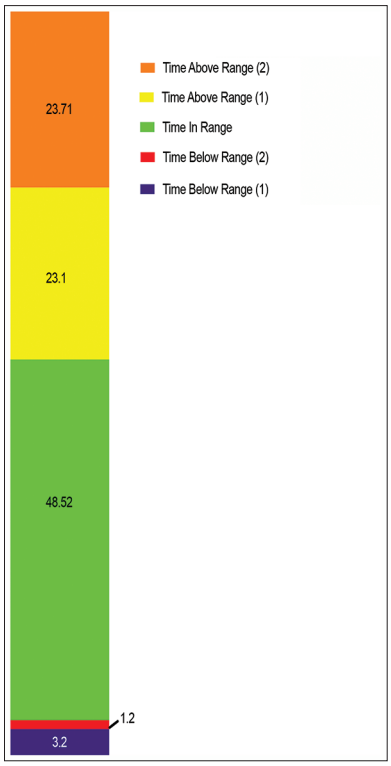

Figure 2: Percentage of time in ranges in 14 days. TIR = Percentage of time in range (70-180 mg/dL, 3.9-10.0 mmol/L), TBR (Level 1) = percentage of time below range (TBR) level 1 (<70-54 mg/dL, <3.9-3.0 mmol/L), TBR (Level 2) = percentage of time below range (TBR) level 2 (<54 mg/dL, <3.0 mmol/L), TAR (Level 1) = percentage of time above range (TAR) level 1 (>180-250 mg/dL, >10.0 mmol/L), TAR (Level 2) = percentage of time above range (TAR) level 2 (>250 mg/dL, >13.9 mmol/L)

stacked bar graph shows that the percentage of TIR is 48.52%, which is less than the recommended percentage as per the international consensus of continuous glucose monitoring.[25] Consequently, TAR level 2 (23.7%) and TAR level 1 (23.1%) are higher than the n-recommended level, whereas TBR level 2 (3.2%) and TBR level 1 (1.2%) are within the accepted range. The collective TIR graph reflects uncontrolled blood glucose for the participants in the selected time point.

Discussion

The current study showed the majority of the sample exhibited a good sleep quality score and high adherence to the Mediterranean diet, with high HbA1c levels and uncontrolled glucose ranges as measured by the FGM devices. The study findings showed no association with HbA1c% or with FGM parameters with independent variables (sleep pattern and quality and adherence to the MD). Only the sleep latency component was significantly associated with TAR level 1 and TBR level 2 FGM parameters.

Some previous studies have shown a link between glycemic control and sleep latency. Monzon *et al*.[26] reported a representative combination between young children's sleep latency on vacation nights and their glycemic variability (out of normal range) with longer onset latency, increased blood glucose, and higher glycemic variability on vacation nights. The reason for these combinations may be that families wanted minor organized bedtime standards for their children on vacation nights rather than on school nights. That combination noticed between children's glycemic variability and bedtime awakenings on vacation nights advises that young children with TID may be more likely to encounter bedtime awakenings following vacation or weekend days when their blood sugar is more unstable, and young children who had more bedtime awakenings on vacation nights may encounter elevated glycemic variability on the following days.[26] Also, one previous study[27] reported that adults with T1D and poor sleep quality or sleeping ≤6 hours had poorer glycemic control, and those children with T1D had shorter measured sleep duration than children without T1D.

Our data show a medium positive correlation between subjectively measured sleep duration using the PSQI questionnaire and the TIR report with a high KIDMED score. Previous studies showed that sleep duration is also associated positively with fruit and vegetable intake and negatively with sweet and snack consumption and eating outside habits using the KIDMED index. Short sleep duration and poor sleep were associated with an increase in BMI and fat mass and unhealthy eating behaviors.[28]

Another study reported that adherence to the MD was associated with sleep duration, which was found to be adequate in the medium and high adherence to the MD groups. In addition, significant differences in adherence to the MD categories and daytime sleepiness were reported.[29] Interesting associations were noticed between sleep behaviors and adherence to the MD. Good sleep habits had been associated with healthier food manners[30] and higher adherence to the MD,[31] while alterations in sleep quality (sleep patterns and sleep efficiency) had often been associated with unhealthy habits and lifestyle modifications, such as consumption of high-calorie foods and beverages and sedentary lifestyle.[32] Low mean glucose levels, HbA1c, and TAR level 1 of the optimal target were all associated with determinants of the KIDMED score, such as high consumption of fish, and cereals at breakfast, and low consumption of sweets and candies. As previously discussed, for weight, foods rich in nutrients and maintenance of breakfast habits are confirmed as being correlated with better glucose control.[33]

Chaput *et al*.[34] reported that published research in this domain lacked the use of objective measures for sleep duration.

Guedes *et al*. found a difference between the informed sleep duration and the one measured objectively through actigraphy about 1 hour on average (with an SD of around 2 hours). There is an overdue of objective measures of sleep duration compared to the subjective method.[35]

The current study shows a medium positive correlation between sleep duration measured using the PSQI questionnaire and sleep duration objectively measured by the Fitbit watch, with a correlation value of 0.388, $P = 0.007$. Jeon *et al*.[36] showed that most parent-reported measures of children's sleep did not hugely correlate with objective measures and child reports. Sleep patterns in T1D children vary across countries with the different impacts of culture. It is also necessary to examine the impact of culture on sleep patterns in children with T1D within different contexts. Indecisive results of some of these studies reported a correlation between actigraphy and PSQI with consideration of sleep efficiency, total sleep time, under-estimated sleep latency, and wake after sleep onset.[37]

A previous study examined sleep components through seven nights of actigraphy measures, sleep diaries, and parents' reports and assessed agreement between these three measures [38]. They found a good level of agreement between actigraphy and sleep diary for bedtime and wake-up time, as for the sum of sleep time obtained during school days. The evaluation of sleep duration through school days also showed satisfactory agreement, albeit to a lesser extent, regarding the vast individual differences between the two measures.[39]

Some previous studies support the notion of a positive relationship between sleep duration and adherence to the MD, including one conducted in Italy in 2017 on 690 children aged 9 to 11[40] and another conducted in Portugal in 2020 on 890 elementary school-aged children.[41] In contrast, our current study found no correlation between adherence to the MD and sleep duration and a Spanish study involving 309 children aged 8 to 13.[42] On the other hand, a recent study found an association between hours of sleep and adherence to the MD; for children with decent sleep duration, the odds ratio for poor to moderate adherence to the MD was 0.282 [95% confidence interval (CI), 0.109–0.681; P 0.05].[43]

The overall glycemic control and glycemic variability evaluated in our sample using analysis of FGM parameters were below the recommended range as per international consensus and recommended clinical targets of continuous glucose monitoring.[23,25] The mean of daily differences (MODD) shows high glucose variability at the same time on different days. Moreover, CONGA (continuous overlapping net glycemic action (60.44)) shows poor glycemic variability as well since it is above the cut-off described by Hill *et al*.[43] The current finding suggests that the high glycemic variability and poor glycemic control are not necessarily associated with changes in sleep quality and dietary patterns, at least in our sample of children and adolescents with T1D. These outcomes highlight the importance of further studies to explore the possible correlation and association of predictors of glycemic control and variability among a similar population of children and adolescents with T1D. Our findings are not consistent with those[26] who found a strong correlation between sleep quality and glycemic control in patients with T1D.

Our study showed a high compliance rate on complete research data among participants with 47 children out of 51 children. In addition to that, the study manages to compare a wide range of data, the independent variables against several dependent variables collected depending on both blood tests and FGM output. In contrast, most published studies relied only on one method, either subjective or objective. Last, the collected data in the study were recorded by the interviewer and not self-reported. However, the current study entails some limitations that should be taken into consideration when interpreting the current results. First, the inherent limitations of the observational cross-sectional design, in addition to the absence of intervention in such an observational study, make it challenging to infer concrete associations or causality. Data collection for the study was done on a relatively small sample from two hospitals in Sharjah using a convenience sampling technique, which therefore calls for care when generalizing the data. The data were collected during spring break, during which the children were on a school vacation. This might lead to the data being a little different from if they were collected during their school days, especially for sleep duration data.

Conclusion

In conclusion, glycemic control is associated in part with sleep quality parameters among young patients with T1D. In addition, improved diet quality and sleep quality and quantity may be associated with improved glycemic control and are partly inter-correlated with each other among these patients. Having individualized glycemic control (using CGM) and sleep measurement (using Fitbit) are more consistent with the T1D management guidelines and expect to have more precise and close management for diabetes. Long-term, controlled intervention research is warranted for more elaboration on the impact of healthy dietary and lifestyle habits on glycemic control among young patients with T1D.

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Data availability statement

Data will be available upon a special request to the main investigator.

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Conflicts of interest

There are no conflicts of interest.

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Supplementary Table 1: Sociodemographic of children's parents

Variable	Category	Father *n* (%)	Mother *n* (%)
Age (Years)	20-39	14 (29.3%)	24 (51.1%)
	40-59	31 (66.0%)	23 (48.9%)
	>60	2 (4.3%)	-
Educational level	High school equivalent	14 (29.8%)	14 (29.8%)
	Bachelor's	26 (55.3%)	29 (61.7%)
	Graduate	7 (14.9%)	4 (8.5%)
Employment (hours/day)	Employed (1-9)	29 (61.7%)	19 (40.4%)
	Employed (>9)	14 (29.8%)	4 (8.5%)
	Not employed	4 (8.5%)	24 (51.1%)

Supplementary Table 2: Correlations of HbA1c% and FGM parameters and the Fitbit (PA level and sleep duration), KIDMED adherence scale and, sleep quality

Variable (*n*=47)	HbA1c percentile	PSQI	Sleep duration PSQI	KIDMED	Fitbit sleep duration	(TAR) level 2	(TAR) level 1	(TBR) level 1	(TBR) level 2
HbA1c percentile									
PSQI	0.153								
	(0.306)								
Age	0.176	0.011							
	(0.249)	(0.943)							
Weight	-0.115	0.358							
	(0.443)	(0.014) *							
Sleep duration (PSQI)	0.087	-0.403							
	(0.560)	(0.005)**							
KIDMED	-0.206	-0.256	0.296						
	(0.164)	(0.083)	(0.043) *						
Fitbit sleep duration	0.174	-0.310	0.388	-0.080					
	(0.243)	(0.034)*	(0.007) **	(0.593)					
(TAR) Level 2	0.749	0.125	0.118	-0.239	0.294				
	(0.001) *	0.402	(0.428)	(0.105)	(0.045) *				
(TAR) Level 1	-0.210	-0.282	0.049	-0.022	-0.212	-0.191			
	(0.157)	(0.055)	(0.743)	(0.884)	(0.153)	(0.199)			
(TIR)	-0.718	-0.037	-0.175	0.309	-0.244	-0.918	-0.122		
	(0.001) **	(0.803)	(0.238)	(0.035) *	(0.098)	(0.001)**	(0.413)		
(TBR) Level 1	-0.128	0.017	0.133	-0.112	0.066	-0.386	-0.289		
	(0.392)	(0.907)	(0.374)	(0.454)	(0.659)	(0.007)**	(0.048) *		
(TBR) Level 2	0.104	0.112	0.008	-0.147	-0.010	-0.156	-0.215	0.698	
	(0.487)	(0.453)	(0.959)	(0.324)	(0.944)	(0.294)	(0.147)	(0.001)**	
Glucose variability	0.298	0.112	0.100	-0.111	0.233	0.094	-0.384	0.609	0.613
	(0.042) *	(0.452)	(0.503)	(0.460)	(0.114)	(0.530)	(0.008)**	(0.001)**	(0.001)**

Supplementary Table 3: Cross-tabulation, Chi-square, Odds ratio, and 95% CI (Categorical variables, 2×2) of the HbA1c% and FGM parameters and the Fitbit (sleep duration) and KIDMED scale (*n*=47)

Variable	KIDMED		Fitbit sleep duration	
	High adherence	Low adherence	Good	Bad
HbA1c (%)				
Controlled	9 (19.1%)	1 (2.1%)	1 (2.1%)	9 (19.1%)
Uncontrolled	26 (56.5%)	10 (21.7%)	15 (31.9%)	22 (46.8%)
OR (95% CI)	3.462 (0.387–30.958)		0.163 (0.019–1.424)	
P	0.244		0.071	
(TAR) Level 2				
Acceptable	4 (8.5%)	-	-	4 (8.5%)
Unacceptable	31 (67.4%)	11 (23.9%)	16 (34.0%)	27 (57.4%)
OR (95% CI)	1.355 (1.131–1.622)		1.593 (1.265–2.005)	
P	0.241		0.133	
(TAR) Level 1				
Acceptable	18 (39.1%)	6 (13.0%)	9 (19.1%)	15 (31.9%)
Unacceptable	17 (37.0%)	5 (10.9%)	7 (14.9%)	16 (34.0%)
OR (95% CI)	0.882 (0.227–3.436)		1.371 (0.408–4.614)	
P	0.857		0.609	
TIR				
Acceptable	4 (8.5%)	-	-	4 (8.5%)
Unacceptable	31 (67.4%)	11 (23.9%)	16 (34.0%)	27 (57.4%)
OR (95% CI)	1.355 (1.131–1.622)		1.593 (1.265–2.005)	
P	0.241		0.133	
(TBR) Level 1				
Acceptable	25 (54.3%)	6 (13.0%)	10 (21.3%)	21 (44.7%)
Unacceptable	10 (21.7%)	5 (10.9%)	6 (12.8%)	10 (21.3%)
OR (95% CI)	2.083 (0.516–8.407)		0.794 (0.225–2.802)	
P	0.297		0.719	
(TBR) Level 2				
Acceptable	22 (47.8%)	7 (15.2%)	8 (17.0%)	21 (44.7%)
Unacceptable	13 (28.3%)	4 (8.7%)	8 (17.0%)	10 (21.3%
OR (95% CI)	0.967 (0.237–3.949)		0.476 (0.138–1.639)	
P	0.963		0.236	
Glucose variability				
Acceptable	9 (19.6%)	5 (10.9%)	2 (4.3%)	12 (25.5%)
Unacceptable	26 (56.5%)	6 (13.0%)	14 (29.8%)	19 (40.4%)
OR (95% CI)	0.415 (0.102–1.698)		0.226 (0.044–1.176)	
P	0.215		0.063	

Cut-off points (good level of the variables). *Dependent variables: HbA1c% <7%, (TAR) time above range Level 2 <5%, (TAR) time above range Level 1 <25%, (TIR) time in range >70%, (TBR) time below rage level 1 <4%, (TBR) time below rage level 2 <1%, and glucose variability ≤36%. *Independent variables: KIDMED 8-12 is good, ≥11,500 steps were good, ≥60 min were counted as good, ≥9-12 h for 4-12 years old child and ≥8-10 h for 13-18 years old child good sleep duration per day

Supplementary Table 4: Cross-tabulation, Chi-square, Odds ratio, and 95% CI (Categorical variables, 2×2) of the FGM parameters and the PSQI sleep components (*n*=47)

Variable	Total PSQI		Sleep Quality		Sleep latency		Sleep duration		Sleep disturbances		Sleep dysfunction	
	Good	Bad	Good	Bad	Good	Bad	Good	Bad	Good	Bad	Good	Bad
HbA1c percentile												
Controlled	9 (19.1%)	1 (2.1%)	10 (21.3%)	-	9 (19.1%)	1 (2.1%)	10 (21.3%)	0	10 (21.3%)	-	10 (21.3%)	-
Uncontrolled	34 (72.3%)	3 (6.4%)	35 (74.5%)	2 (4.3%)	27 (57.4%)	10 (21.3%)	35 (74.5%)	2 (4.3%)	35 (74.5%)	2 (4.3%)	36 (76.6%)	1 (2.1%)
OR (95% CI)	0.794 (0.074-8.576)		1.057 (0.979–1.142)		3.333 (0.373–29.775)		1.057 (0.979–1.142)		1.057 (0.979–1.142)		1.028 (0.974–1.084)	
P	0.630		0.452		0.259		0.452		0.452		0.599	
(TAR) Level 2												
Acceptable	4 (8.5%)	-	4 (8.5%)	-	4 (8.5%)	-	4 (8.5%)	-	4 (8.5%)	-	4 (8.5%)	-
Unacceptable	39 (83.0%)	4 (8.5%)	41 (87.2%)	2 (4.3%)	32 (68.1%)	11 (23.4%)	41 (87.2%)	2 (4.3%)	41 (87.2%)	2 (4.3%)	42 (89.4%)	1 (2.1%)
OR (95% CI)	1.103 (1.002–1.213)		1.049 (0.982–1.120)		1.344 (1.128–1.601)		1.049 (0.982–1.120)		1.049 (0.982–1.120)		1.024 (0.978–1.072)	
P	0.524		0.659		0.248		0.659		0.659		0.758	
(TAR) Level 1												
Acceptable	21 (44.7%)	3 (6.4%)	22 (46.8%)	2 (4.3%)	15 (31.9%)	9 (19.1%)	23 (48.9%)	1 (2.1%)	22 (46.8%)	2 (4.3%)	23 (48.9%)	1 (2.1%)
Unacceptable	22 (46.8%)	1 (2.1%)	23 (48.9%)	-	21 (44.7%)	2 (4.3%)	22 (46.8%)	1 (2.1%)	23 (48.9%)	-	23 (48.9%)	-
OR (95% CI)	0.318 (0.031–3.306)		0.917 (0.813–1.034)		0.159 (0.030–0.843)		1.045 (0.062–17.765)		0.917 (0.813–1.034)		0.958 (0.882–1.042)	
P	0.317		0.157		0.020*		0.975		0.157		0.322	
(TIR)												
Acceptable	4 (8.5%)	-	39 (83.0%)	2 (4.3%)	4 (8.5%)	-	4 (8.5%)	-	4 (8.5%)	-	4 (8.5%)	-
Unacceptable	39 (83.0%)	4 (8.5%)	6 (12.8%)	-	32 (68.1%)	11 (23.4%)	41 (87.2%)	2 (4.3%)	41 (87.2%)	2 (4.3%)	42 (89.4%)	1 (2.1%)
OR (95% CI)	1.103 (1.002–1.213)		0.951 (0.888–1.019)		1.344 (1.128–1.601)		1.049 (0.982–1.120)		1.049 (0.982–1.120)		1.024 (0.978–1.072)	
P	0.524		0.580		0.248		0.659		0.659		0.758	
(TBR) Level 1												
Acceptable	28 (59.6%)	3 (6.4%)	29 (61.7%)	2 (4.3%)	26 (55.3%)	5 (10.6%)	30 (63.8%)	1 (2.1%)	29 (61.7%)	2 (4.3%)	30 (63.8%)	1 (2.1%)
Unacceptable	15 (31.9%)	2 (2.1%)	16 (34.0%)	-	10 (21.3%)	6 (12.8%)	15 (31.9%)	1 (2.1%)	16 (34.0%)	-	16 (34.0%)	-
OR (95% CI)	0.622 (0.059–6.514)		0.935 (0.853–1.026)		3.120 (0.775–12.564)		2.00 (0.117–34.240)		0.935 (0.853–1.026)		0.968 (0.908–1.032)	
P	0.690		0.299		0.101		0.626		0.299		0.468	
(TBR) Level 2												
Acceptable	28 (59.6%)	1 (2.1%)	29 (61.7%)	-	25 (53.2%)	4 (8.5%)	29 (61.7%)	-	28 (59.6%)	1 (2.1%)	29 (61.7%)	-
Unacceptable	15 (31.9%)	3 (6.4%)	16 (34.0%)	2 (4.3%)	11 (23.4%)	7 (14.9%)	16 (34.0%)	2 (4.3%)	17 (36.2%)	1 (2.1%)	17 (36.2%)	1 (2.1%)
OR (95% CI)	5.60 (0.535–58.628)		1.125 (0.955–1.325)		3.977 (0.963–16.429)		1.125 (0.955–1.325)		1.647 (0.097–28.094)		1.059 (0.947–1.184)	
P	0.114		0.067		0.048*		0.067		0.728		0.199	
Glucose variability												
Acceptable	12 (25.5%)	2 (4.3%)	13 (27.7%)	1 (2.1%)	11 (23.4%)	3 (6.4%)	13 (27.7%)	1 (2.1%)	14 (29.8%)	-	13 (27.7%)	1 (2.1%)
Unacceptable	31 (66.0%)	2 (4.3%)	32 (68.1%)	1 (2.1%)	25 (53.2%)	8 (17.0%)	32 (68.1%)	1 (2.1%)	31 (66.0%)	2 (4.3%)	33 (70.2%)	-
OR (95% CI)	0.387 (0.049–3.068)		0.406 (0.024–6.994)		1.173 (0.261–5.282)		0.406 (0.024–6.994)		1.065 (0.976–1.161)		0.929 (0.803–1.074)	
P	0.355		0.523		0.835		0.523		0.347		0.121	

*Cut-off points for Total PSQI scores ≤5 scores were good, the sleep seven components' scores of 0 and 1 were good, and scores of 2 and 3 were bad for each PSQI component