The Associations of the Longitudinal Glucose Sensor Data for Children having Type 1 Diabetes and Parental Characteristics

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Abstract: There is limited knowledge concerning the way parental behaviour and attitudes, affect glycemic outcomes in children with Type 1 diabetes melllitus (T1DM), wearing a continuous glucose monitoring (CGM) sensor. The aim of this research is to assess the association of CGM sensor data with parental diabetes caregiver characteristics. The cross-sectional study involved N=79 pediatric patients with T1DM who had worn a CGM sensor for more than 180 days before the study. Sensor wear time, time below range (TBR, 3.0 – 3.9 mmol/L), time in range (TIR, 3.9 – 10.0 mmol/L), and time above range (TAR, 10.0 – 13.9 mmol/L) were calculated retrospectively for 180 days. Both the children and their parents were surveyed. Parental self-efficacy in diabetes management and fear of hypoglycemia were assessed with the Parental Self-Efficacy Scale for Diabetes Management (PSESDM) and the Hypoglycemia Fear Survey (HFS) questionnaires. Data was analyzed using descriptive methods, Spearman rho correlation and multiple linear regression. In the total sample, the

mean sensor wear time was 77.0% ±20.1. The TBR, TIR and TAR were 2.6% ±1.7, 63.0% ±13.8, and 24.6%±8.6, respectively. Parental PSESDM score was correlated with the TIR, while HFS was correlated with the TBR. Regression analysis revealed that children's sensor wear time and parents' PSESDM score are positively associated with the TIR. Our results highlight the relevance of CGM sensor wearing for diabetes outcomes and draw attention to the role of parents in the treatment of their diabetic child. Parental self-efficacy in diabetes management deserves particular attention, as it was found to be an important factor in achieving the desired glycemic control.

Keywords: pediatric diabetes; digital medical devices; continuous glucose monitoring; patient-reported outcome

1 Introduction

Pediatric type 1 diabetes mellitus (T1DM) is a common chronic disease with an increasing worldwide incidence and prevalence. [1, 2] In addition to its health consequences, it also causes a significant economic and social burden. [3] Furthermore, due to the need to adapt to strict therapeutic regimens and lifestyle discipline, T1DM poses a challenge not just to affected children but to their caregivers as well. [4]

Successful management of T1DM is primarily based on accurate and regular blood glucose measurement and tailored treatment. Novel advanced digital health technologies can offer a number of benefits in the management of T1DM compared to traditional treatment methods (blood glucose level measurement from fingertips, insulin dosing pen), contributing to the maintenance of children's balanced health state and the achievement of the desired glycemic outcomes. [5] The increasingly available and used continuous glucose monitoring (CGM) sensors offer significant advances and improvements. [6] The CGM sensors are digital devices applied to the skin measuring interstitial blood glucose level 24 hours a day (usually every five minutes) and transmit the measurement data regularly to a display platform (e.g., mobile telephone). A number of studies have investigated how CGM data can be used to achieve glycemic targets, such as improving nighttime blood glucose prediction, reducing the frequency of hypo- and hyperglycemic episodes and ensuring adequate blood glucose control. [7-10] The information obtained from CGM can be used to predict physical activity and thereby may support automated therapeutic modifications such as decisions to change insulin dosing. [11] Furthermore, CGM also serves as the primary data source for various advanced technologies used in the treatment of T1DM, including closed-loop insulin delivery systems that implement artificial intelligence (AI) and machine learning (ML)-based algorithms. [12] Artificial pancreas is one example of these systems, which showed superior efficacy in blood glucose control and risk of hypoglycemia compared to conventional insulin therapy. [13, 14]

Advanced technologies such as CGM and subcutaneous insulin infusion may have an impact not only on the physical but also on the emotional status and the relationship of pediatric T1DM patients and their caregivers. [15, 16] Continuous insulin pump therapy has been reported to have positive life effects, such as improving the health-related quality of life (HRQoL) of children with T1DM and increasing their independence in insulin dosing. [17-19] Furthermore, in addition to reducing patients' hemoglobin A1c (HbA1c) and severe hypoglycemic episodes, real-time CGM data sharing may improve parents' diabetes distress, hypoglycemic confidence and overall well-being. [20] However, negative effects have also been described, as the quantity of information received may lead to increased anxiety. [21] Conflicts between parents and children may also arise as a result of strict supervision and monitoring. [21] Other problems and adverse events related to wearing a CGM have also been identified, such as bulkiness of the transmitter, difficulties with carrying the device or itching and irritation at the site of application. [15] Taken together, these negative effects can lead to a reduction in therapeutic compliance and sensor wear time, and consequently to a deterioration in glycemic outcomes. There is an increasing need to address these controversies surrounding the use of CGM sensors, as illustrated by the fact that social aspects, patient-reported outcomes and experiences are primary considerations in the decision-making about the reimbursement of digital health technologies. [22]

The primary aim of the present study was to investigate how CGM data, with a special focus on sensor-wearing habits and glycemic parameters, are related to parental diabetes caregiver' attitudes and well-being. Secondarily, we aimed to investigate the associations between CGM data and HRQoL outcomes of T1DM children.

2 Methods

2.1 Study Design and Patient Population

A cross-sectional survey was carried out in a Hungarian university pediatric diabetology center between 2021 and 2022, of which the details have been published elsewhere. [23] In brief, children aged 8-14 years, living with T1DM for more than 3 months and their parents (or caregivers) attending the Pediatric Center at Semmelweis University Budapest (Hungary) were invited to participate in the study. Parents' and children's basic demographic characteristics, data on household and childcare circumstances were recorded by self-reports. Medical information about children, such as height, weight, disease duration, duration of treatment at the medical center, type of insulin treatment and glucose measurement (pen, pen + sensor, pump, pump + sensor) and duration of device usage (only for pump+sensor users) were obtained from treating diabetologists. Standard measurement tools,

introduced in the next chapter, were used to assess parents' HRQoL, capability well-being, self-perceived efficacy in diabetes management, fear of hypoglycemia and electronic health literacy. Children's general and diabetes-specific HRQoL were also examined with standard questionnaires.

As the current study is focused on the assessment of CGM data, only parent-child dyads who had started to use a CGM sensor (either with a pen or insulin pump) for at least 180 days before the date of completion of the cross-sectional questionnaire were included in the analysis. Longitudinal sensor data were obtained retrospectively for 180 days. Children treated with an insulin pump used either MiniMed 640G or MiniMed 780G.

Participants provided their written informed consent when entering the study. Ethical approval was obtained from the Hungarian Medical Research Council (IV/3848-1/2021/EKU; BMEÜ/1620-1/2022/EKU).

2.2 Standard Measurements

2.2.1 Parental Survey

Parental Self-Efficacy Scale for Diabetes Management (PSESDM)

The PSESDM was developed as a tool to examine parents' self-perceived confidence in managing their child's diabetes. [24] There are eight statements in the questionnaire. Responses are operated on a 5-level scale (1 - strongly disagree, 5 - strongly agree). Scores assigned to responses are added up to calculate the final score which ranges from 8 to 40. Higher score indicate better confidence in managing diabetes.

Hypoglycemia Fear Survey (HFS)

The Hypoglycemia Fear Survey (HFS) measures how much parents fear that their child have a hypoglycemic episode. [25] It consists of two parts, the first assessing what actions parents take to avoid hypoglycemia and the second assessing concerns over hypoglycemia. Parents have to rate on a 5-level scale how much a given statement is true for them with a higher score indicating better agreement (0 – never, 4 – almost always). Individual scores are added up to calculate the final score (range: 0-100). The higher the score the higher the fear of hypoglycemia.

eHealth Literacy Scale (eHEALS)

The eHEALS aims to assess the respondent's self-reported ability to find, understand and use electronic health information. It comprises 4 domains (awareness, searching for information, evaluation of health resources and utilization) with two statement in each. For each statement, the level of agreement can be indicated on a 5-level scale (1 – strongly disagree; 5 – strongly agree). Scores given for each item are added up to calculate the final score (range: 8-40). A higher

score indicates better electronic health literacy. The recent study used the Hungarian language version of the eHEALS. [26]

ICEpop CAPability measure for Adults (ICECAP-A)

The ICECAP-A is a measure of the capability well-being of adults aged between 18 and 65 in the following five domains: attachment, stability, achievement, enjoyment, and autonomy. Responses can be given on a 4-level scale with 1 indicating the worst (no capability) and 4 the best (full capability) well-being the respondent experience at the time of completion. Scores given for each domain are combined with country-specific value sets to calculate the final index score (score range 0-1). In the present study, the Hungarian language version and value set were used. [27, 28]

EQ-5D-5L

The EQ-5D-5L questionnaire was developed to assess respondents general HRQoL in five domains: Mobility, Self-care, Usual activities, Pain/discomfort and Anxiety/depression. [29] Respondents can indicate their actual health problems in each domain on a five-level Likert scale (1 - no problems, 5 – unable to/ extreme problems). Index values can be calculated by assigning weights (utility values) to each of the problem levels indicated in each dimension and then subtracting these weights from 1. Index values are anchored at 1 (full health) and 0 (a health state as bad as being dead), but values lower than 0 are also possible representing health states considered worse than death. In this study, the Hungarian language version and utility value set of the questionnaire were used (score range -0.848 - 1). [30] There is an additional item, the EQ VAS, that measures respondents' actual self-reported health on a visual analog scale (VAS) where 0 represents the worst and 100 the best imaginable health.

2.2.2 Child's Survey

EQ-5D-Y-3L

The EQ-5D-Y-3L was designed to specifically measure children's general health-related quality of life in five domains: mobility; taking care of myself; doing usual activities; feeling pain or discomfort; and feeling worried, sad, or unhappy. [31] Respondents can indicate their actual problem levels from 1 (no problems) to 3 (a lot of problems). The EQ-5D-Y-3L index value is calculated by combining item-level responses with utility values. In the present study, the Hungarian value set (score range -0.485 - 1) was used for this purpose. [32] A VAS is also part of the measurement, which is a vertical scale where respondents can report their current health state from 0 (worst imaginable health) to 100 (best imaginable health).

PedsQL (generic and diabetes-specific module)

The PedsQL questionnaire assesses children's health-related quality of life. Its generic module has 23-items organized in 4 modules: physical functioning,

emotional functioning, social functioning and school functioning. [33] The diabetes-specific module (PedsQL Diab version 3) consists of 28-items, covering 5 domains: symptoms of diabetes, difficulties with treatment, acceptance of treatment, worry about the disease, and difficulties with communication. [34] In both modules, respondents can indicate their answers on a 5-level scale (0 – never, 4 – almost always). The final score is calculated by transforming scores given for each answer to a scale ranging from 0 – 100 using inverse scoring (the original scores are transformed as 0=100, 1=75, 2=50, 3=25, and 4=0) followed by the calculation of their arithmetic mean. Higher scores indicate better HRQoL in both the generic (PedsQL) and the diabetes-specific (PedsQL Diab v3) modules.

2.3 Statistics

The statistical analysis was performed in Stata version 17 (StataCorp LCC, Texas, USA). Sample characteristics were assessed by descriptive statistical methods. Differences between subgroups were compared using Chi-squared, Welch and ANOVA tests. The associations between continuous variables were analyzed by Spearman correlation (string: > 0.5; moderate: 0.5–0.3; weak: < 0.3). [35] The significance level was $p<0.05$ in all statistical test.

Longitudinal glucose data recorded by the CGM sensor was used to calculate the following metrics to describe the sensor wearing habits of participants:

- Sensor Wear Time (SW): Percentage of total time the CGM sensor was active during the 180-day interval studied. SW was calculated by dividing the number of recorded glucose values by the hypothetical maximum number of glucose values in the 180 days (n=51840) and then multiplying by 100. The SW, therefore, expresses the proportion of sensor wearing but does not provide information on how it was distributed over the 180-day period. According to the 2017 ADA recommendation on clinical outcomes, the desired target of sensor wear time is 70% on a weekly average. [36]
- Number of CGM sensor non-adherence periods: The number of periods in the 180-day interval studied when the CGM sensor was not worn continuously for at least 12 hours. The 12-hour limit was set to filter out missed sensor wear for reasons other than non-adherence, such as technical problems and sensor unavailability.
- The average length of CGM sensor non-adherence periods, expressed in hours: The average length of periods in the 180-day interval studied when the CGM sensor was not worn continuously for at least 1 hour. Calculated for each participant by dividing the sum of the length of periods of at least one hour by the number of periods.

From longitudinal glucose data recorded by the CGM sensor, the following glycemic outcomes were calculated for each participant:

- Sensor glucose, 180-day average (mmol/L): The simple average of glucose values recorded every 5 minutes by the CGM sensor over the entire 180-day interval.
- Coefficient of Variation: The ratio of the standard deviation (SD) and the mean of CGM glucose values, multiplied by 100 to express as a percentage. CV is used to measure glycemic variability in a given period. [37] According to the American Diabetes Association (ADA) 2017 consensus guideline on the use of continuous glucose monitoring, stable glucose levels are defined as a CV <36%, and unstable glucose levels are defined as CV ≥36%'. [38]
- Time in Therapeutic Range (TIR): Time spent in the therapeutic target range (3.9 – 10.0 mmol/L), expressed as a percentage. [39] Calculated only for the period during which the CGM was worn.
- Time Below Range (TBR): Time spent below the therapeutic target range, expressed as a percentage. In the study, two ranges were defined: 3.0 – 3.9 mmol/L (low) and 2.2 – 3.0 mmol/L (very low). [39] Calculated only for the period during which the CGM was worn.
- Time Above Range (TAR): Time spent above the therapeutic target range, expressed as a percentage. In the study, two ranges were defined: 10.0 – 13.9 mmol/L (high) and 13.9 – 22.2 mmol/L (very high). [39] Calculated only for the period during which the CGM was worn.

Regression

Covariates associated with TIR were investigated by multiple linear regression. A total of four models were developed. Covariates were added sequentially so that every successive model included the covariates from the previous one. The first model included treatment modality, children's characteristics (sex, age, diabetes duration), and parents' characteristics (sex, age, education). Children's HRQoL data (PedsQL, PedsQL Diab score and EQ-5D-Y-3L index value) and parents' HRQoL (EQ-5D-5L index value), well-being (ICECAP-A score), self-efficacy in diabetes management (PSESDM score), fear of hypoglycemia (HFS score) and electronic health literacy (eHEALS score) were added to the second and third models, respectively. In the fourth model, the coefficient of glucose variation, total sensor wear time, and the number and average length of sensor non-adherence periods were added.

3 Results

3.1 Sample Characteristics

The total number of parent-child dyads who used a CGM sensor either with an insulin pen or pump was 85 in total. There were 6 children for whom CGM data was available for less than 180 days and therefore were excluded, resulting in a total of 79 parent-child dyads in the analysis.

Parents' mean age was 43.2 years ±4.9 (range 32-62), 82.3% of them were women. No meaningful differences were observed in parental HRQoL (EQ-5D-5L), well-being (ICECAP-A), self-reported efficacy in diabetes management (PSESDM), and electronic health literacy (eHEALS) by socio-demographic subgroups. Fear of hypoglycemia as measured by the HFS, was significantly higher among mothers than fathers. Results are shown in Table 1.

Table 1
Parental characteristics

Variables	**N (%)**	**PSESDM (Score range: 8-40)**	**HFS (Score range: 0-100)***	**eHEALS (Score range: 8-40)**	**ICECAP-A (Score range: 0-1)**	**EQ-5D-5L index (Score range: -0.848-1.000)**
		Mean Score (SD)				
Total sample	79 (100.0)	33.8 (5.3)	40.6 (12.1)	31.8 (4.2)	0.90 (0.11)	0.97 (0.07)
Sex		p=0.681	**p=0.030**	p=0.189	p=0.140	p=0.430
Men	14 (17.7)	34.3 (5.0)	34.8 (9.9)	33.1 (3.5)	0.93 (0.06)	0.98 (0.04)
Women	65 (82.3)	33.7 (5.3)	41.8 (12.3)	31.6 (4.3)	0.89 (0.12)	0.97 (0.07)
Age group**		p=0.531	p=0.624	p=0.575	p=0.515	p=0.161
25-34	5 (6.3)	34.8 (6.3)	36.2 (5.5)	29.6 (6.6)	0.94 (0.07)	0.97 (0.04)
35-44	39 (49.4)	33.4 (5.5)	41.7 (12.6)	31.8 (4.1)	0.90 (0.11)	0.96 (0.09)
45-54	34 (43.0)	34.2 (4.9)	39.6 (12.4)	32.3 (4.0)	0.91 (0.11)	0.99 (0.02)
55-64	1 (1.3)	27.0 (-)	50.0 (-)	30.0 (-)	0.76 (-)	0.87 (-)
Education		p=0.311	p=0.524	p=0.346	p=0.692	p=0.478
Primary	4	31.3	39.5	31.5	0.93	0.98

Variables	N (%)	PSESDM (Score range: 8-40)	HFS (Score range: 0-100)*	eHEALS (Score range: 8-40)	ICECAP-A (Score range: 0-1)	EQ-5D-5L index (Score range: -0.848-1.000)
		Mean Score (SD)				
	(5.1)	(6.5)	(8.7)	(5.8)	(0.08)	(0.04)
Secondary	35 (44.3)	33.1 (5.7)	38.9 (11.3)	31.1 (4.3)	0.89 (0.11)	0.96 (0.10)
Tertiary	40 (50.6)	34.6 (4.7)	42.1 (13.1)	32.6 (3.9)	0.91 (0.12)	0.98 (0.03)
Residence		p=0.604	p=0.201	p=0.300	p=0.410	p=0.295
Capital	21 (26.6)	33.9 (5.4)	41.8 (11.7)	30.8 (4.5)	0.88 (0.12)	0.99 (0.02)
Town	41 (51.9)	34.2 (4.6)	38.4 (11.2)	32.0 (4.3)	0.91 (0.10)	0.97 (0.08)
Village	17 (21.5)	32.6 (6.5)	44.4 (14.3)	32.8 (3.4)	0.90 (0.13)	0.95 (0.07)
Monthly net income per capita (missing=20)		p=0.410	p=0.910	p=0.754	p=0.279	p=0.163
1. quintile	8 (13.6)	30.6 (7.6)	39.5 (9.7)	31.1 (4.9)	0.86 (0.11)	0.91 (0.17)
2. quintile	6 (10.2)	32.5 (5.5)	42.5 (11.6)	30.8 (3.5)	0.93 (0.05)	0.99 (0.02)
3. quintile	8 (13.6)	34.1 (5.1)	43.6 (15.3)	31.5 (4.2)	0.82 (0.22)	0.97 (0.04)
4. quintile	2 (3.4)	30.0 (8.5)	34.5 (10.6)	30.0 (2.8)	0.97 (0.04)	1.00 (0.00)
5. quintile	35 (59.3)	34.1 (4.4)	40.3 (14.1)	32.5 (4.0)	0.90 (0.10)	0.98 (0.05)

*Higher score indicates greater fear of hypoglycemia.

** There were no parents under 25 years of age in the sample.

Differences between groups were compared using Welch's and ANOVA tests.

Percentages may not add up to 100% due to rounding.

Abbreviations: SD – Standard Deviation; Parental Self-Efficacy Scale for Diabetes Management – PSESDM; Hypoglycemia Fear Survey – HFS; e-Health Literacy Scale – eHEALS

In the total sample, children's mean age was 11.9 ±1.7 (range: 8-15) years and 48.1% of them were girls. There were N=43 and N=41 patients treated with pen+sensor and pump+sensor, respectively. The average duration of diabetes was

4.8 ±2.5 years which was significantly ($p<0.001$) higher in the pump+sensor group (5.8 ±2.6 years) compared to the pen+sensor group (3.7 ±2.0 years).

3.2 Sensor-Wearing Habits and Glycemic Outcomes

In the total sample, the mean of the total sensor wear time was 77.0% ±20.1 (range 20.3 – 97.0), and 58 (73.4%) patients reached the clinical target of 70% average wear time. During the 180-day interval studied, the average number of sensor non-adherence periods (i.e., minimum 12 consecutive hours without the sensor) was 9.7 ±8.0 (range 0 – 26). Seventy two patients had at least one sensor non-adherence period lasting 12 hours or longer. Among them, the average length of sensor non-adherence periods was 102.6 ±215.9 (range 12.0 – 1701.1) hours. Table 2 shows details of CGM sensor non-adherence periods over the 180-day interval studied. Sensor non-adherence periods ranging from 12 to 24 hours occurred in 67 patients, while there were 55 who had periods when the sensor was continuously not worn between 1 day and 30 days. In addition, the sample included 15 patients who had non-adherence periods longer than 30 days.

Table 2
CGM sensor non-adherence periods during the 180-day period

	Time range of sensor non-adherence		
	12h – 24h	1 day – 30 days	30days <
Number of patients (Total N=79)	67	55	15
Number of non-adherence periods *Mean* ±SD *(range)*	5.3 ±4.2 (1-16)	7.3 ±6.2 (1-23)	1.1 ±0.6 (1-2)
Length of non-adherence periods *Mean* ±SD *(range)*	17.4 ±3.7 hours (12.0 – 24.0)	3.5 ±3.9 days (1.0 – 27.1)	50.5 ±23.9 days (30.1-114.7)

All in all, the average 180-day glucose value was 9.0 ±1.2 mmol/L (range 6.9-12.8) and patients spent on average 63.0%, ±13.8 (range: 26.8-84.4) of their total time in the TIR (3.9 – 10.0 mmol/L). In addition, they spent 2.6%, ±1.7 (range: 0.1-8.1) of their time TBR (3.0 – 3.9 mmol/L) and spent TAR (10.0 – 13.9 mmol/L) nearly the quarter of their time on average (24.6%, ±8.6; range 9.5-53.3). Patients' duration of disease, duration of treatment at the medical center and duration of device use (the latter only for pump+sensor users) were not associated with sensor-wearing habits and glycemic outcomes (data not shown but available upon request).

Sensor-wearing habits and glycemic outcomes by treatment modalities are shown in Table 3. Total sensor wear time and the number and length of sensor non-adherence periods did not differ by treatment modalities. Also, no significant differences were observed in case of glycemic outcomes, except for TBR (2.2 – 3.0 mmol/L), which was slightly higher among those using pen+sensor.

Table 3
Children's CGM sensor wearing habits and glycemic outcomes by treatment modalities

Variables	Total sample (N=79)	Treatment modality		
		Pen+sensor (N=39)	Pump+sensor (N=40)	p-value
	Mean ±SD (range)			
Total Sensor Wear Time, %	77.0 ±20.1 (20.3-97.0)	80.0 ±17.0 (36.3-96.8)	74.2 ±22.6 (20.3-97.0)	0.202
Number of sensor non-adherence periods	9.7 ±8.0 (0-26)	9.7 ±7.7 (0-23)	9.8 ±8.4 (0-26)	0.953
Length of sensor non-adherence periods	102.6 ±215.9 (12.0 – 1701.1)	53.3 ±56.6 (12.0-248.3)	154.7 ±297.4 (12.7-1701.1)	0.055
Sensor glucose, 180 day average mmol/L	9.0 ±1.2 (6.9-12.8)	9.1 ±1.3 (6.9-12.4)	8.8 ±1.1 (6.9-12.8)	0.281
Coefficient of Variation, %	35.3 ±4.2 (22.8-49.4)	36.0 ±4.9 (22.8-49.4)	34.7 ±3.4 (26.5-41.1)	0.189
TBR (very low), % 2.2 – 3.0 mmol/L	0.7 ±0.9 (0-6.7)	0.9 ±1.2 (0-6.7)	0.5 ±0.4 (0.01-1.5)	**0.047**
TBR (low), % 3.0 – 3.9 mmol/L	2.6 ±1.7 (0.1-8.1)	2.9 ±1.9 (0.1-8.1)	2.4 ±1.5 (0.3-6.2)	0.247
TIR, % 3.9 – 10.0 mmol/L	63.0 ±13.8 (26.8-84.4)	60.4 ±15.0 (26.8-84.4)	65.6 ±12.2 (28.6-83.1)	0.093
TAR (high), % 10.0 – 13.9 mmol/L	24.6 ±8.6 (9.5-53.3)	25.3 ±9.5 (9.5-53.3)	23.9 ±7.6 (1.0-37.2)	0.459
TAR (very high), % 13.9 – 22.2 mmol/L	9.1 ±7.7 (0.3-38.0)	10.6 ±8.2 (0.8-35.9)	7.6 ±7.0 (0.3-38.0)	0.090

Abbreviations: SD – Standard Deviation; Time Below Range – TBR, Time In Range – TIR, Time Above Range – TAR

Differences between treatment modalities are compared with a two-sample t-test.

Total sensor wear time over the entire 180-day period showed a strong, negative correlation with the number and length of sensor non-adherence periods ($r = -0.64$, $p<0.001$ and $r = -0.84$, $p<0.001$, respectively) but not with glycemic outcomes. The 180-day average glucose value was strongly associated with the percentage of time spent in different glucose ranges, but not with the coefficient of glucose variation and sensor-wearing habits. It was also observed that the coefficient of glucose variation strongly correlated with TBR (very low) and TBR (low), and it was weakly correlated with TAR (very high), but no association was observed with TIR. Results are shown in Figure 1.

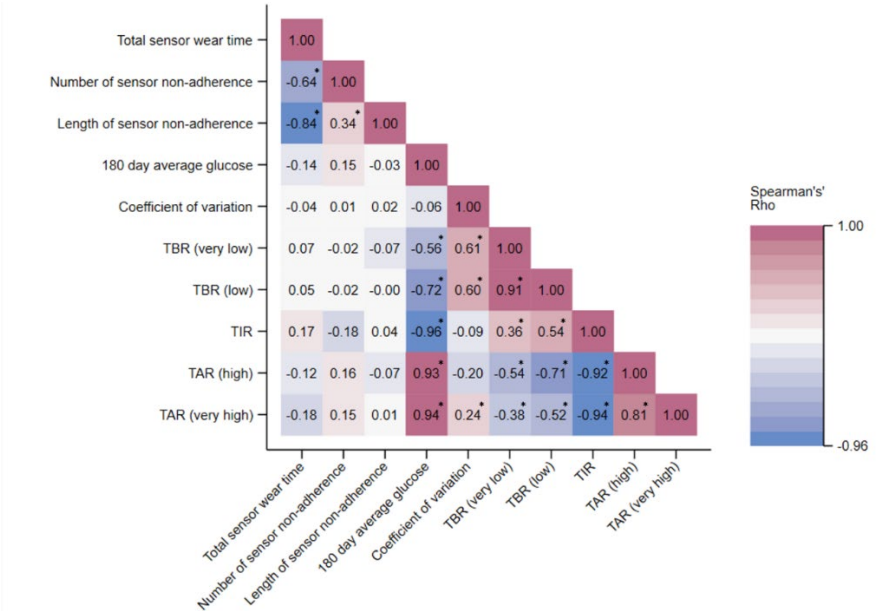

Figure 1

The correlation matrix of sensor wearing habits and glycemic outcomes

Numbers are Spearman correlation coefficients.

The number of observations was N=79 in all cases.

* $p<0.05$

Abbreviations: TBR – Time below Range; TIR – Time in Range; TAR – Time above Range

3.3 Associations of Sensor Data with Parental Diabetes Caregiver Characteristics and Wellbeing

Sensor-wearing habits and glycemic outcomes did not differ significantly by parental demographics (data not shown but available upon request).

No correlation was observed between metrics of sensor-wearing habits and parental diabetes caregiver characteristics and wellbeing. (Table 4)

Regarding glycemic outcomes, parental self-efficacy for diabetes management (PSESDM score) correlated positively with the TIR and negatively with the TAR (high), TAR (very high) and the 180-day average sensor glucose value. The eHEALS showed a weak, positive association with the TIR and also a weak but negative association with the TAR (very high). The HFS correlated weakly with the coefficient of variation, the TBR (low) and TBR (very low), but not with the other outcomes. Parental wellbeing (ICECAP-A) showed significant association with three out of the seven glycemic outcomes, namely with the 180-day average sensor glucose value, TIR and high TAR (very high). Parental health-related quality

of life (EQ-5D-5L index) did not correlate with any of the glycemic outcomes. (Table 4)

Table 4
The correlation of parental health-related quality of life (EQ-5D-5L), well-being (ICECAP-A), self-reported efficacy in diabetes management (PSESDM), fear of hypoglycemia (HFS) and electronic health literacy (eHEALS) with CGM sensor wearing habits and glycemic outcomes

	Parental characteristics				
	PSESDM	**HFS**	**eHEALS**	**ICECAP-A**	**EQ-5D-5L**
CGM sensor wear habits					
Total sensor wear time	0.127	0.153	-0.058	0.017	-0.103
Number of sensor non-adherence periods	-0.078	-0.156	0.012	-0.038	0.159
Length of sensor non-adherence periods	0.046	-0.111	0.015	0.182	-0.008
Glycemic outcomes					
Sensor glucose, 180 day average	**-0.406***	-0.148	-0.190	**-0.238***	-0.206
Coefficient of variation	-0.192	**0.258***	-0.176	-0.154	0.055
TBR (very low), 2.2 – 3.0 mmol/L	0.037	**0.249***	-0.039	-0.027	0.139
TBR (low), 3.0 – 3.9 mmol/L	0.166	**0.241***	0.093	0.044	0.156
TIR, 3.9 – 10.0 mmol/L	**0.445***	0.091	**0.229***	**0.255***	0.176
TAR (high), 10.0 – 13.9 mmol/L	**-0.330***	-0.212	-0.185	-0.146	-0.140
TAR (very high), 13.9 – 22.2 mmol/L	**-0.450***	0.040	**-0.250***	**-0.260***	-0.163

Numbers are Spearman correlation coefficients.
The number of observations was N=79 in all cases
* $p<0.05$
Correlations between sensor-wearing habits and glycemic outcomes are omitted as they were presented separately in Table 3.

3.4 Associations of Sensor Data with Health-related Quality of Life Outcomes of Children

Regarding children's characteristics, sensor-wearing habits and glycemic outcomes did not differ by sex. Patients' age negatively correlated with sensor wear time (r=-0.342, p=0.002) and TIR (r=-0.235, p=0.037) and positively with mean sensor

glucose (r=0.233, p=0.039) and the length of sensor non-adherence periods (r=0.309, p=0.006).

Children's PedsQL, PedsQL Diab and EQ-5D-Y-3L scores did not correlate with sensor-wearing habits and glycemic outcomes. Results of the correlation analysis of children's quality of life outcomes and sensor data are shown in Table 5.

Table 5

The correlation of children's generic (PedsQL, EQ-5D-Y-3L) and diabetes-specific (PedsQL Diab) health-related quality of life with CGM sensor-wearing habits and glycemic outcomes

	PedsQL	**PedsQL Diab**	**EQ-5D-Y-3L**
CGM sensor wear habits			
Total sensor wear time	-0.049	0.066	-0.078
Number of sensor non-adherence periods	0.098	-0.020	0.078
Length of sensor non-adherence periods	0.088	0.021	0.140
Glycemic outcomes			
Sensor glucose, 180 day average	-0.150	-0.144	-0.080
Coefficient of variation	0.030	-0.150	0.040
TBR (very low), 2.2 – 3.0 mmol/L	0.021	-0.069	0.079
TBR (low), 3.0 – 3.9 mmol/L	0.040	-0.025	0.069
TIR, 3.9 – 10.0 mmol/L	0.163	0.164	0.090
TAR (high), 10.0 – 13.9 mmol/L	-0.151	-0.086	-0.095
TAR (very high), 13.9 – 22.2 mmol/L	-0.155	-0.185	-0.082

Numbers are Spearman correlation coefficients.

The number of observations was N=79 in all cases

* $p<0.05$

Correlations between sensor-wearing habits and glycemic outcomes are omitted as they were presented separately in Table 3.

3.5 Regression Analysis

Table 6 shows the results of the regression analysis. In the first to third models, treatment modality, child's age, parental age and sex, and the PSESDM score were significantly associated with the TIR. In the final model, which explained 97.6% of the variance, the PedsQL score and the PSESDM score kept their significance and also strengthened their positive association. Among sensor wearing habits, only the total sensor wear time was associated with the TIR.

Table 6
Regression on determinants of children's time in range (TIR) result

Variables	Models			
	1	2	3	4
	Regression coefficients			
Treatment modality				
Pump + Sensor	**9.48***	6.43	4.92	3.91
Child's sex (ref: Boy)				
Girl	1.52	1.72	-1.83	-5.08
Child's age	-0.45	-1.36	**-1.77***	-0.85
Diabetes duration	-0.18	0.07	-0.19	0.49
Parent's sex (ref: Man)				
Women	**15.39****	**10.72***	5.61	2.86
Parent's age	**1.24*****	0.55	0.07	-0.26
Parent's education (ref: Primary)				
Secondary	-1.47	-3.25	-3.03	-5.18
Tertiary	-5.13	-7.56	-8.82	-10.30
PedsQL score		0.32	**0.50***	**0.59****
PedsQL Diab score		0.04	-0.23	-0.25
EQ-5D-Y-3L		18.82	-15.66	-25.23
EQ-5D-5L			-2.81	-12.31
ICECAP-A			26.69	25.07
PSESDM			**0.87***	**0.97***
HFS			0.19	0.19
eHEALS			0.43	0.22
Coefficient of Variation				0.08
Total Sensor Wear Time				**0.26***
Number of sensor non-adherence periods				0.02
Length of sensor non-adherence periods				0.01
R-squared	*0.949*	*0.958*	*0.974*	*0.976*

* p<.05; ** p<.01; *** p<.001
The number of observations was N=79 in all models

4 Discussion

We have assessed longitudinally collected CGM sensor data of children with T1DM and their association with parental characteristics, including diabetes caregiver attitudes, health-related quality of life and well-being, measured with standard tools.

In terms of sensor-wearing adherence, no associations were observed with either parental characteristics or the children's characteristics and their glycemic outcomes. However, the average sensor glucose level and time in the therapeutic range showed a significant association with parental diabetes management self-efficacy and well-being. In addition, a significant association was observed between the child's glycemic variability and parental fear of hypoglycemia. Multivariate analysis revealed that CGM sensor wear time, parents' self-perceived efficacy in diabetes management, and the children's general health-related quality of life were important predictors of the time spent in the therapeutic target range, considered an important, clinically relevant endpoint in T1DM care.

Although parents' involvement is important in T1DM children's proper disease management [40], there is currently limited knowledge on how parental self-efficacy affects their child's disease status, particularly glycemic control. [24] It has been found that parental self-efficacy in diabetes management, as measured by the PSESDM questionnaire, was associated with HbA1C. [23] However, to the best of our knowledge, its relationship with glycemic parameters derived from CGM sensor data has not yet been investigated. This gap in the literature may be partially filled by the results of the present study as the correlation analysis suggests that children whose parents have higher self-efficacy tend to spend more time in the therapeutic target range and have fewer hyperglycemic episodes. However, it is important to highlight, that no correlation was observed with either level 1 or level 2 hypoglycemia (time below range).

The evidence on the effect of the child's CGM sensor use on the parent's fear of hypoglycemia is controversial. Some studies have described that CGM usage reduces parental fear of hypoglycemia, while some authors argue that under certain circumstances, permanent contact with the sensor and information overload may have the opposite effect. [41] Furthermore, there is also a debate about how other factors such as the frequency and severity of hypoglycemic episodes influence parental fears. [41] In our study, we found that despite the continuous CGM sensor usage, parental fear of hypoglycemia was present and was significantly higher in mothers compared to fathers. Furthermore, it was associated with glycemic variability and, importantly, an almost equal correlation was found with the time spent in level 1 and level 2 hypoglycemic glucose ranges. Due to the cross-sectional design of our study, it was not possible to examine how fear of hypoglycemia changes over time, but based on these observations, it can be assumed that fear of hypoglycemia is much more influenced by the frequency of hypoglycemic episodes rather than their severity.

Other parental characteristics, such as well-being, e-health literacy and quality of life have also been less studied in this context. An interim analysis has previously shown that capability well-being as measured by ICECAP-A was associated with HbA1C levels. [42] In our current study examining the subgroup of CGM sensor wearers, we also found associations with parental well-being and glycemic outcomes, as both the average CGM sensor glucose and the time spent in the

therapeutic range were positively correlated with the ICECAP-A score. Similarly, in the case of eHealth literacy, we observed a weak association with time in the therapeutic range but not with average CGM sensor glucose level, results that are consistent with previously published findings where there was no association between the eHEALS score and HbA1C level. [23] In contrast, the parental general quality of life was not associated with any indicators of the child's glycemic status. These observations are particularly important, as to the best of our knowledge, this was the first study to examine and report parents' EQ-5D-5L score in relation to their child's CGM sensor data.

A regression analysis was performed, as a deeper understanding of the relationship between individual characteristics can be achieved in a multivariate setting, when it is possible to simultaneously adjust for the effects of several background variables. Our target variable was the time spent in the therapeutic range, a clinically relevant endpoint that is associated with microvascular events and patients' quality of life. [43] The analysis confirmed that pediatric T1DM patients whose parents have higher self-efficacy spend significantly more time in the therapeutic target range. In addition, it was observed that the time spent in the therapeutic range was also higher for patients who wore the sensor more often and who had a higher overall quality of life, as measured with the PedsQL questionnaire. However, characteristics such as parental eHealth literacy and well-being, which were associated with the time spent in the therapeutic range in the univariate analysis, lost their significance in the regression. These results highlight which factors may have a particular influence on the time spent in the target range when the effects of several factors are jointly present.

Our results also suggest that the mode of insulin delivery is a less important factor when it comes to sensor-wearing habits and glycemic outcomes, as pen and pump users were almost equally represented and no differences in the parameters studied were observed between them. In general, participants had adequate adherence to sensor wearing, with 77% average sensor wear time in the total sample and with more than two-thirds of patients achieving the American Diabetes Association (ADA) defined 70% average sensor wear time. [36] An important question of the study was what temporal pattern sensor non-wearing follows: whether patients remove the sensor for many short or fewer but longer periods. The correlation analysis revealed that patients with lower total sensor wear time usually remove the it for longer intervals.

In previous studies high glycemic variability was a marker of metabolic instability and was associated with a higher risk of hypoglycemia. [44, 45] Our results are in line with these observations, as we found that patients with higher glucose variability typically spent more time outside the therapeutic range, especially in the low glucose range. Furthermore, we also observed that while the average glucose level was strongly correlated with time spent in the therapeutic range and also with time spent above the range, its association with time spent below the range was significantly weaker but still strong and significant. This result suggests that there

is a significant risk of hypoglycemia even when blood glucose levels are generally high, so that poorly managed patients are simultaneously exposed to the consequences of both hyper- and hypoglycemia. These observations highlight the importance of CGM measurement and continuous glucose monitoring as a means of accurately following and assessing patients' glycemic status, whereas HbA1C (a routinely used test that shows the average of the blood sugar level over the past 90 days) alone is not a suitable tool to evaluate hypoglycemia and glucose variability. [36, 46]

There are limitations of the study that need to be considered for the interpretation of our results. The study was conducted in a single clinical center, which limits the generalizability of the results to the entire population of pediatric T1DM patients and their caregivers. Furthermore, the glycemic outcomes examined may be influenced by other characteristics not investigated in the present analysis, such as the frequency with which parents intervene in the treatment of their diabetic child. Assessing the effect of these factors would be an important avenue for future research. In addition, the validity of the Hungarian version of the PSESDM questionnaire has not yet been determined, which calls for further research in the future.

Conclusions

This study provides valuable baseline information, as it is the first to report a descriptive analysis of CGM sensor parameters and assess their association with parental characteristics, such as self-efficacy in diabetes management, fear of hypoglycemia, and well-being in a sample of pediatric T1DM patients and their caregivers. The results highlight the relevance of wearing a CGM sensor for diabetes outcomes, as children, who have higher adherence, tended to spend more time in the therapeutic target range.

Furthermore, our findings draw attention to the role of parents in the treatment of their diabetic child, particularly to their self-efficacy in diabetes management, which was consistently found to be an important factor in achieving the desired glycemic control. The results of this study can be particularly useful for technology developers, aid clinical therapeutic decisions and support reimbursement decisions for digital health technologies.

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