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Glycemic trends and reduced insulin requirements in adolescents with type 1 diabetes during a therapeutic recreational camp: Insights from continuous glucose monitoring

Boglárka Varga[1], Enikő Nemes-Nagy[2*], Boglárka Mikes-Jakab[3], Melinda Kórodi[4]

1. Department of Internal Medicine I, George Emil Palade University of Medicine, Pharmacy, Science, and Technology of Targu Mures, Romania
2. Department of Chemistry and Medical Biochemistry, George Emil Palade University of Medicine, Pharmacy, Science, and Technology of Targu Mures, Romania
3. Faculty of General Medicine, George Emil Palade University of Medicine, Pharmacy, Science, and Technology of Targu Mures, Romania
4. Diabetology Outpatient Unit, SC Marmed SRL, Targu Mures, Romania

ABSTRACT

Background: Appropriate management of glycemic control in type 1 diabetes mellitus (T1DM) is challenging. Severe hypoglycemia represents a feared acute complication. Diabetes camps provide ideal settings for implementation of Continuous Glucose Monitoring (CGM) technologies.

Methods: A prospective interventional study was conducted on 41 T1DM adolescents between August 28- September 2, 2023 in a therapeutic recreational camp in Șăulia, Romania. Key features: use of Dexcom One sensor with a receiver, six scheduled meals per day, standardized hypoglycemia protocol, therapeutic activities with physical exercise. Demographic data, information regarding insulin types, doses, carbohydrate intake, CGM data were collected in the first (D1) and last (D5) days of the camp.

Results: Mean age of participants was 14.9 years±1.25 (SD), 61% were females, 71% from urban areas. Of all participants, 42% had continuous subcutaneous insulin infusion (CSII) therapy and 71% previously used CGM devices. Time in range (TIR) levels increased (D1: 59.7% vs. D5: 65.4%, p=0.152) due to reduction of both time below range (TBR: D1: 6.4% vs. D5: 2.1%, p=0.061) and time above range (TAR: D1: 33.78% vs. D5: 32.03%, p=0.623). Significant reduction in insulin doses (p=0.001) occurred (D1: 52.5±18.45 IU vs. D5: 47.6±15.63), more evident in females, and in patients on basal-bolus (BB) insulin therapy. Insulin sensitivity factor also increased significantly (D1: 38.7±19.34 mg/dL vs. D5: 42.4±15.5 mg/dL, p=0.050).

Conclusions: Improved glycemic control was observed along with a decline in insulin requirements during the study. A strictly controlled environment, adapted diet and modern tehnology contribute to the achievement of better metabolic control in T1DM.

Keywords: continuous glucose monitoring system, glycemia, insulin, therapeutic recreational camp, type 1 diabetes mellitus

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INTRODUCTION

Type 1 diabetes mellitus (T1DM) is an autoimmune disorder defined by the destruction of pancreatic β-cells resulting in absolute insulin deficiency, which primarily affects children and adolescents [1] Young age is one of the most critical periods associated with glycemic oscillations, due to the variable dietary patterns, physical activity, pubertal development, and associated hormonal fluctuations, which lead to worsened glycemic control [2,3].

The management of T1DM is multidisciplinary, including medical, technological, psychosocial approaches. Advances in technology are bringing progress in the field of diabetes care not only through the use of insulin pen devices and smart insulin pens, but also by CGM systems and insulin pump therapy [4].

Recent advances in personalized medical technologies — encompassing high-throughput diagnostic platforms and artificial intelligence-driven data analytics — have markedly improved the accuracy, efficiency, and clinical relevance of laboratory medicine. These developments facilitate individualized diagnostic strategies that support enhanced disease stratification, more precise therapeutic monitoring, and ultimately, improved patient care outcomes [5].

* Corresponding author: Eniko Nagy Nemes, Department of Chemistry and Medical Biochemistry, George Emil Palade University of Medicine, Pharmacy, Science, and Technology of Targu Mures. E-mail: eniko.nemes-nagy@umfst.ro

Glycemic control is improved mostly by the possibility to monitor blood glucose level fluctuations using CGM devices, regardless of the insulin administration method [4]. This approach reduces the burden of self-monitoring of blood glucose (SMBG) including pain, inconvenience, embarrassment and the possibility of user error [6]. The most feared acute complications of T1DM, nocturnal and asymptomatic hypoglycemic episodes, can also be detected [4]. Moreover, these developments provide real-time data on current glycemia and on the tendency of blood glucose fluctuations [4].

Detailed CGM reports with specific predefined, individualized targets offer another angle of glycemic management in T1DM [4].

The history of diabetes camps dates back to the period of insulin discovery in 1922, when the first diabetes camp was organized by Leonard F.C. Wendt, MD, in Michigan in 1925 [7]. The world's longest operating camp for children with T1DM was founded in 1929 in Cleveland by Dr. Henry John, named Camp Ho Mita Koda, which still welcomes nearly 350 campers every summer [8].

By 2023, studies showed a significant increase in the number of diabetes camps around the world. Current estimates indicate that over 500 diabetes camps worldwide serve more than 30,000 children annually [8]. Camps specifically designed for youth with T1DM aim to provide a traditional camping experience, allowing attendees to meet other participants who share the same condition, in a medically safe environment [9]. In therapeutic recreation camps the priority is focused on enhancing campers' coping ability, increasing resilience, and providing guidance for more conscientious diabetes management [9].

The initial implementation of CGM systems in pediatric patients with T1DM within a camp setting was designed to evaluate the efficacy of CGMs in a real-life environment. Following the implementation of this initiative, a number of additional CGM devices were examined for their effectiveness [10]. Concurrently, other methods such as centralized, remote glucose level monitoring were employed for enhanced follow-up and reduction of time spent in hypoglycemia, during diabetes camps [11].

In recent years, the use of mobile phones and other wireless devices has become more widespread in this age group and concerns have been raised about the potential negative impact of these devices [12]. A high percentage of adolescents engage in extensive smartphone use, resulting in chronic sleep deprivation, reduction of face-to-face interactions, poor academic performance, worsened mental health and even self-harming actions [13]. The complete elimination of mobile phone use has been found to increase engagement in activities, promote quality time spent together and foster closer connections [14].

The purpose of this study was to evaluate CGM data in adolescents with T1DM during a therapeutic recreation camp organized in a controlled environment.

METHODS

Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki. The use of collected data was approved by the medical committee of the organizing association (Asociația Yuppi Camp). Parents were informed about the purpose and methodology of the study, and written informed consent for data use was obtained from all parents on the first day of the camp during the check-in procedure. Participation was voluntary, and all data were anonymized to ensure confidentiality.

Study design and setting

A descriptive interventional study was conducted at a therapeutic recreation camp between August 28 and September 2, 2023 in Șăulia, Mureș County, Romania.

Participants

Participants were selected for the study based on predefined inclusion criteria: previously confirmed T1DM, age < 18 years, good general health, and acceptance to participate in the camping experience. Exclusion criteria were: acute glycemic exacerbation in the past three months resulting in severe episodes of hypoglycemia or hospitalization for diabetic ketoacidosis.

Data collection

Baseline data including gender, residence, prior CGM use were noted. Information was collected and double checked with parents at check-in, by the medical team, regarding the number of meals consumed per day, daily carbohydrate (CH) intake and its distribution among the meals, the type of long- and short acting insulin used, BB insulin doses, basal rates for insulin pump users, correction factors and insulin-to-carbohydrate ratios at home. Modifications of these metabolic parameters during the camp were also recorded. More information on previous hypoglycemic episodes, allergies, special dietary needs for lactose intolerance and celiac disease were collected.

Dexcom One CGM systems were applied to every participant by members of the medical team. CGM devices used prior to the camp were replaced with Dexcom One CGM devices. Furthermore, personalized setting adjustments were made on every sensor in order to receive warning notifications before glycemic extremes were reached.

Medical supervision and camp structure

During the camp, the participants were under continuous surveillance by the medical staff. This included one board-certified diabetologist, four diabetology resident doctors, two clinical nutritionists, and one nurse specialized in diabetes care. Night shifts were covered by two members of the medical team and two camp volunteers. Within the camp, the medical team established a medical office that ensured a fully equipped environment not only for the treatment of extreme glycemic values, but also for the therapy of other pediatric conditions.

Being a 5-day long therapeutic recreational camp, the participants had the opportunity to engage in a variety of recreational, experience-based, social and physical activities such as horse riding, archery, indoor climbing, canoeing for at least 3 hours per day. During these activities multiple medical checkpoints were established throughout the camping area to ensure better medical supervision.

A well-defined number of glycemic measurements and hypoglycemia correction protocol were applied. Restriction from physical activity was applied if glycemic values were above 250 mg/dL (13.9 mmol/L), which was managed immediately by taking a break from the activity, hydration, and a 20 minute walk. If glycemic values rose above 300 mg/dL, rapid acting analog insulin was administered for correction.

The camp provided a controlled environment setting that incorporated six meals served daily at scheduled hours, according to a pre-established nutritional plan. Menus were prepared according to nutritionist's instructions, the carbohydrate amount per meal was pre-counted by the medical team and insulin doses were adjusted before meals in collaboration with every participant.

All attendees were using the Dexcom One CGM system, connected to an external receiver device. This setup eliminated the use of mobile phones entirely during the camp stay.

Information on children's well-being was communicated to parents by phone once during the camp period and on the request of the participant or the parent.

Glycemic monitoring and hypoglycemia protocol

A comprehensive record of each participant's data was documented on designated monitoring charts. These charts encompassed various parameters, including blood glucose level measurements using CGM device readings before each meal and at night, with hourly measurements recorded. Fasting blood glucose levels were recorded at 8:00 AM using both a standard glucometer (Accu-Chek Instant, Roche) and CGM data.

Additional measurements were performed in response to symptoms of hypoglycemia or when hyperglycemia was indicated by the CGM receiver. À jeun capillary readings were compared with the CGM data to assess the accuracy of the CGM device.

The amount of carbohydrate consumed at every meal, and insulin types and doses administered were also noted. Glycemic values under 70 mg/dL (3.9 mmol/L) were treated according to a well-established hypoglycemia correction protocol, which allowed participants to attend the activity after reaching normoglycemia. The first step of the hypoglycemia protocol consisted of temporarily suspending the basal insulin rate for insulin pump users. If the hypoglycemic episodes were severe or recurrent, adjustments were made concerning basal infusion rates or basal insulin doses.

If above 70 mg/dL (3.9 mmol/L) and with hypoglycemia symptoms one dextrose tablet (2 g CH) and two biscuits (10 g CH), in total 12 grams CH were administered. For level 1 hypoglycemic episodes (54-70 mg/dL, 3.0-3.9 mmol/L) participants received 100 mL fruit juice (12 g CH) and two biscuits (10 g CH), for a total of 22 grams of carbohydrates. For level 2 hypoglycemia (< 54 mg/dL, < 3.0 mmol/L) 100 mL fruit juice (12 g CH), two dextrose tablets (4 g CH), two biscuits (10 g CH), totaling 26 grams of CH, were administered. Intranasal glucagon or intravenous infusion of glucose was available for the treatment of severe hypoglycemia. Follow-up blood glucose measurements were made every 10-15 minutes after the hypoglycemic episode to ensure the onset of normoglycemia.

CGM report analysis

Before participants' check-out from the camp, CGM reports of every participant were downloaded and reports were generated using the Dexcom Clarity application. Based on the collected information, a comparison was conducted between the first and fifth day.

Data obtained from these reports were defined as the following: TIR or the percentage of time in which a person's blood glucose levels remained between 70-180 mg/dL (3.9-10 mmol/L), considered optimal glycemia in T1DM. Level 1 hypoglycemia (TBR1) was the time spent in the 70 mg/dL (3.9 mmol/L) to 54 mg/dL (3 mmol/L) range, respectively level 2 hypoglycemia (TBR2) under 54 mg/dL (<3 mmol/L).

Level 1 hyperglycemia (TAR1) signified the time spent having blood glucose level between 181-250 mg/dL (10.1-13.9 mmol/L), and level 2 hyperglycemia (TAR2), was time spent above 250 mg/dL (>13.9 mmol/L). Other parameters included in the study consisted of coefficient of variation, glucose management indicator and mean glucose levels.

Statistical analysis

Descriptive statistics were performed for all variables. The normality of continuous variables was assessed using the Shapiro–Wilk test. Continuous variables were summarized as means ± standard deviations (SD) for normally distributed data and as medians with interquartile ranges (IQR) for non-normally distributed data. Categorical variables were reported as absolute frequencies and percentages.

To compare CGM data from the first and last day, a paired t-test was used for variables with a normal distribution, while the Wilcoxon signed-rank test was applied for non-normally distributed variables. All tests were two-tailed, and p-values ≤ 0.05 were considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 28.0.

RESULTS

Forty-one adolescents attended the therapeutic recreation camp, of whom twenty-five (60.97 %) were females, with an average age of 14.9 years ± 1.25 (SD), min. 13, max. 17 years. The majority of participants (70.73%) were from urban areas.

Prior to the camp, 71 % of participants were using CGM devices for blood glucose monitoring. The type of CGM devices previously used were as follows: Dexcom One (37.9%), Medtronic Guardian 3 (34.4%), Medtronic Guardian 4 (10.34%), and Freestyle Libre 2 (17.24%).

Nearly half (41.5%) of all attendees were using different types of CSII therapy (Figure 1). BB insulin therapy was used by 58.5% of participants prior to the camp, which consisted mostly of first-generation basal analog insulin Glargine (91.67%) under different brand names and second-generation analog insulin Degludec in 8.33%. Bolus insulin was mainly represented by the analog insulin Aspart, which was utilized by 15 adolescents (62.5%). Other bolus insulin types such as Lispro (20.8%), faster Aspart (12.5%), and Glulisine (4.1%) were also used.

During the camp, the Dexcom One CGM system was applied and continuously used by all participants, without any technical issues. The mean fasting blood glucose levels measured by the glucometer at 8:00 AM demonstrated a significant correlation with the corresponding CGM sensor readings (147.2 ± 32.2 mg/dL vs. 138.4 ± 43.5 mg/dL; p=0.040), with an average difference of approximately 6.33%.

We assessed five days of CGM data obtained from Dexcom One sensors and compared the first and last day results as shown in Table 1 and Figure 2.

The analyzed blood glucose profiles showed a pronounced increase in TIR when comparing D1 to D5 (D1-TIR: 59.7 ± 19.7% vs. D5-TIR: 65.45 ± 17.49%, p=0.152). Also, a decrease in the mean blood glucose level was observed (D1: 162 ± 41.9 mg/dL vs. D5: 159 ± 27.8 mg/dL, p=0.816).

Time spent in both level 1 and level 2 hypoglycemia episodes decreased (D1-TBR1: 3.92% ± 8.32% vs. D5-TBR1: 1.76% ± 3.08%, p=0.193), (D1-TBR2: 2.52% ± 6.47% vs. D5-TBR2: 0.44% ± 1.82%, p=0.063). Hypoglycemia awareness was present at a mean blood glucose level of 65.0 ± 7.2 mg/dL (3.61 ± 0.40 mmol/L).

Also a decrease in the time spent above range was observed (D1-TAR1: 25.6 ± 15.4% vs. D5-TAR1: 21.92 ± 11.5%, p=0.211). However, time spent in level 2 hyperglycemia increased (D1-TAR2: 5.0% ± 10.1% vs. D5-TAR2: 6.5% ± 10.7%, p=0.344). For reference, a glycemic level of approximately 200 mg/dL was associated with the presence of hyperglycemia symptoms (females: 197 mg/dL [10.93 mmol/L];

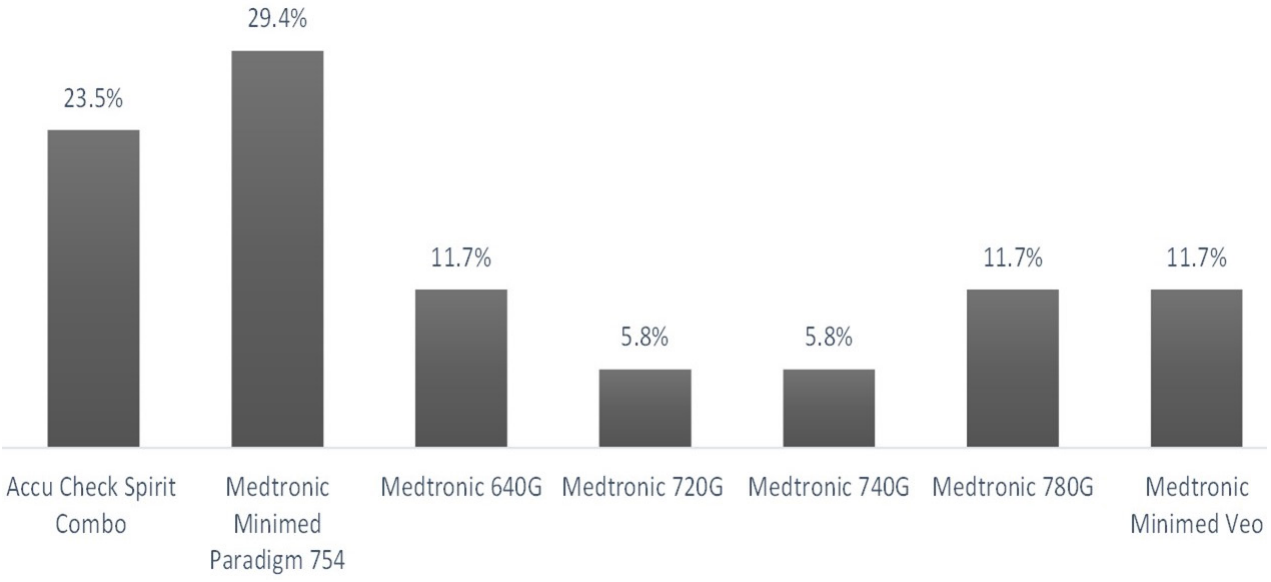

Figure 1. Continuous Subcutaneus Insulin Infusion (CSII) therapy used during the camp

Table 1. Dexcom One CGM parameters and comparison of results on the first and fifth day of camp

Parameter	Average value	Day 1	Day 5	*p* value
Mean blood glucose level (mg/dL)	158.0 ± 25.7 (125.0 – 221.0)	162.0 ± 41.9 (81.0 – 330.0)	159.0 ± 27.8 (109.0 – 214.0)	0.816
Level 2 hyperglycemia (%)	8.70 ± 8.58 (0.00 – 38.00)	5.00 ± 10.10 (0.00 – 14.00)	6.50 ± 10.77 (0.00 – 19.00)	0.344
Level 1 hyperglycemia (%)	22.0 ± 10.4 (7.0 – 54.0)	25.6 ± 15.4 (0.0 – 43.0)	21.9 ± 11.5 (1.0 – 48.0)	0.211
Time in range (%)	64.0 ± 15.6 (26.0 – 92.0)	59.7 ± 19.7 (16.0 – 94.0)	65.4 ± 17.5 (29.0 – 98.0)	0.152
Level 1 hypoglycemia (%)	2.3 ± 2.8 (0.0 – 13.0)	3.92 ± 8.32 (0.0 – 4.0)	1.76 ± 3.08 (0.0 – 0.0)	0.193
Level 2 hypoglycemia (%)	0.84 ± 1.55 (0.00 – 8.00)	2.52 ± 6.47 (0.00 – 0.75)	0.44 ± 1.82 (0.00 – 0.00)	0.063
Coefficient of variation (CV%)	35.5 ± 6.9 (21.0 – 54.0)	29.5 (25.0 – 38.0)	33.5 (28.2 – 36.0)	0.514
MIN value	51.0 ± 12.5 (28.0 – 80.0)	70.5 (53.0 – 92.5)	70.5 (62.2 – 75.5)	0.771
MAX value	333.0 ± 47.0 (217.0 – 401.0)	271.5 ± 57.8 (168.0 – 401.0)	284.0 ± 53.2 (205.0 – 401.0)	0.275

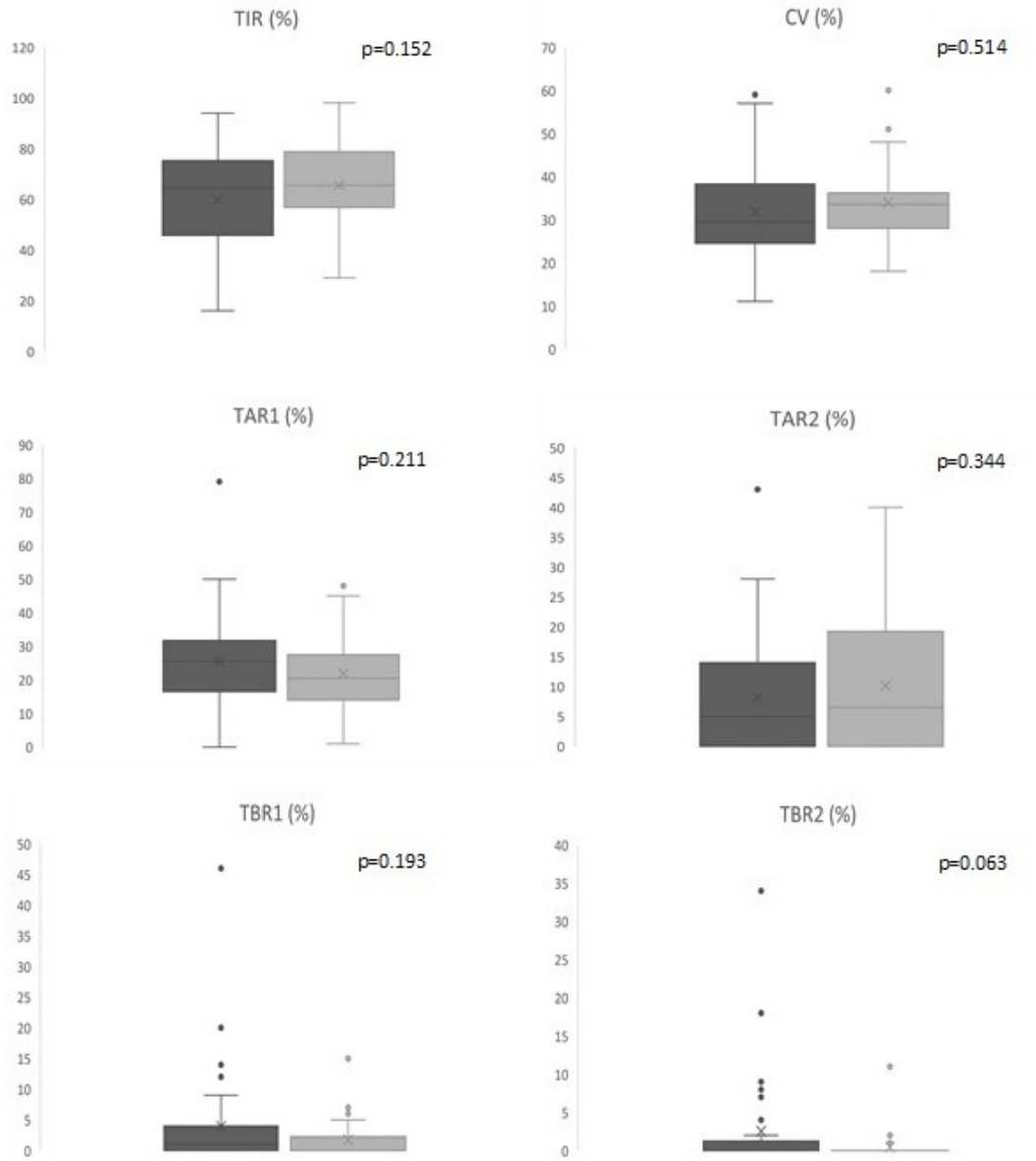

Figure 2. Comparison of CGM parameters during D1 and D5 of the diabetes camp

males: 212 mg/dL [11.76 mmol/L]) and required an insulin correction dose at an average level of 203 ± 26.85 mg/dL (11.27 ± 1.49 mmol/L), as reported by parents.

A 9.4% reduction in total insulin doses was observed, which was a statistically significant result compared to the registered insulin doses at check-in (D1: 52.5±18.45 IU vs. D5: 47.6±15.63 IU, *p*=0.001). This was attributed to the reduction of insulin doses both for prandial and correction administration. Bolus insulin requirement significantly decreased during the camp (D1: 27.23 IU ± 13.61 IU vs. D5: 22.2 IU ±11.1 IU, *p*<0.001). Insulin doses were reduced more among patients treated with BB insulin therapy (D1:30.2 IU vs. D5:23.9 IU, *p*=0.012) than in insulin pump users (D1:22.06 IU vs. D5:18.9 IU, p= 0.021). Here, the dose of basal insulin was significantly reduced (D1:23.7 IU vs. D5: 22.8 IU, *p*<0.042).

Female participants showed a more pronounced reduction in insulin doses (D1: 23.8 IU vs. D5: 18.6 IU, *p*<0.001), whereas in males this reduction was negligible (D1: 32.9 IU vs. D5: 29.2 IU, *p*=0.131).

Insulin sensitivity factor increased significantly during the camp (D1:38.7 ± 19.34 mg/dL vs. D5:42.4 ± 15.5mg/dL *p*=0.050). Coefficient of variation (CV) showed a slight increase (D1: 29.5% and D5:33.5%, *p*=0.514) as shown in Figure 2.

During the camp the amount of carbohydrates consumed increased significantly from 185 gram CH reported on the first day of the camp (± 58 gr CH, min. 75 g CH, max. 330 g CH) to 198 gram CH (± 36.6 g CH, min. 140 g CH , max. 284 g CH, *p*=0.051) on the last day.

CH consumption was more pronounced among females (D1:168.4 g CH vs. D5: 186.3 g CH, *p*=0.009). In male participants a significant decrease in CH consumption was detected at dinner (D1:67.8 g CH vs. D5:54.1 g CH, *p*=0.042), in contrast to females (D1:47.3 g CH vs. D5:50.3 g CH, *p*=0.193). Campers with BB insulin therapy (D1:188.4 g CH vs. D5: 203.1 g CH, *p*=0.052 vs CSII: D1:179.1 g CH vs. D5:192.5 g CH, *p*=0.081) showed a significant increase in total CH consumption.

DISCUSSION

There are few studies published on glycemic monitoring in T1DM patients in camp settings.

The TIR measured during the camp was below the normal value of 70%. Comparatively, we found two studies reporting lower TIR values of 60.35 % and 59.1% [1,3]. In a 2022 article, Nagl et al. published a TIR of 71.9 %. However, in this case it is important to take into account that the number of participants was smaller (n=26) and the camp period was longer (14 days) [15].

To highlight the improvement in glycemic control, a level of 159 mg/dL of mean blood glucose was recorded on the last day of the camp. This result represents an important improvement compared to the aforementioned studies, which concluded with a mean level of blood glucose to be 173.5 mg/dL and 171 mg/dL [3,12].

Concerning TBR, we found similar results both for level 1 and 2 of hypoglycemia. Our results for level 1 hypoglycemia (1.7%) were between the measurement of Gelich S. et al. (2.7 %) and Ata A. et al. (1.41%) [3,11]. We obtained the same results as Gleich S. et al. regarding time spent in severe hypoglycemia, which was 0.4% [11]. This finding was obtained by using our own hypoglycemia protocol, which proved to be applicable, practical, and functional under these conditions.

In the case of TAR, we found similar level 1 hyperglycemia outcomes compared to the aforementioned authors: Gleich S. et al. 38.2 % and 20.5% Ata A. et al [3,11]. However an increase was observed in TAR2, we found a notably better result for level 2 hyperglycemia, of 10.1%, whereas in the two aforementioned studies, values of 17.0% and 14.2% were reported [3,11].

Taking into consideration the lack of published literature on the value of the coefficient of variation, under these controlled conditions our result of 33.9% comes closer to the target value, in comparison with the one published result of 41.2% we found [3].

The decrease in total insulin dose was found to be 9.4%, mainly attributed to the reduced insulin bolus doses. In the study conducted by Nagl et al. the same tendency was found, but with a more pronounced insulin dose reduction of 18% [15].

The improvement in glycemic control and the additional need for insulin dose reduction in parallel with the elevated carbohydrate intake suggest an optimized metabolic state of the participants. The increase in insulin-to-carbohydrate ratio also adds to these findings. We observed a more pronounced metabolic improvement in the case of female participants, which may be due to hormonal fluctuations, but it needs to be further investigated [16].

The Dexcom One CGM system proved to be a safe choice in the camp setting both during the planned activities and overnight. The significant correlation between glucometer and CGM-derived fasting glucose values suggests that the Dexcom One CGM may serve as a reliable alternative for monitoring morning glycemic levels, offering the additional benefits of continuous data collection and enhanced convenience in both clinical and research settings. The observed average difference of 6.33% between the two measurement methods falls within the range of a mean absolute relative difference (MARD) below 10%, which is generally considered acceptable for clinical accuracy and reliability [17].

By using a receiver device, we were able to eliminate mobile phone use during the entire period of the camp, which in our view provided a more suitable environment for youth to connect and engage in social activities. Moreover, in T1DM patients, the use of these devices in real-life settings enables a more dynamic and representative data collection, facilitating a broader and more accurate understanding of glycemic patterns compared to intermittent laboratory-based assessments.

Considering the short period of time that the participants spent in the therapeutic recreation camp, the optimization of blood glucose levels represented a challenge. In our observation, glycemic control may be achieved only by the final day, mainly due to the high contrast between the participant's home environment and camping experience. A longer camping period up to 7 to 10 days could provide more accurate insight into glycemic fluctuations and enable better metabolic control.

It is important to note that during this therapeutic recreational camp considerable changes occurred in the daily routine of the attendees, including the number, quality, and quantity of meals and increased physical activity. The variety of activities and programs offered further contributed to this change. Consequently, perfect blood glucose control during the camp was not expected.

Limitations of our study, apart from the short monitoring period involved, was the lack of information regarding the duration of diabetes, previous glycemic management, and blood glucose control, anthropometric measurements and concrete information on the quality and time spent engaged in physical activity at home. Also, there were no available data on glycemic control after participating in the camp. Further studies should focus on the long-term effects of interventional camp experiences on metabolic control.

CONCLUSIONS

This study demonstrated that under these controlled conditions, using the Dexcom One CGM system and applying protocols for glycemic extremes, within a relative short time-frame a better glycemic status can be achieved in adolescents with T1DM.

ABBREVIATIONS

BB – Basal-bolus

CGM – Continuous Glucose Monitoring

CH – Carbohydrate

CSII – Continuous subcutaneous insulin infusion

CV – Coefficient of Variation

D1 – Day one

D5 – Day five

MARD – Mean absolute relative difference

SD – Standard Deviation

SMBG – Self-monitoring of blood glucose

T1DM – Type 1 diabetes mellitus

TAR – Time Above Range

TAR1 – Level 1 hyperglycemia

TAR2 – Level 2 hyperglycemia

TBR – Time Below Range

TIR – Time in Range

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AUTHORS' CONTRIBUTION

BV – conceptualization, methodology, data collection, data analysis, data visualization, writing draft, Final revision

ENN – data management, writing draft, final revision

BMJ – data management, writing draft, final revision

MK – conceptualization, methodology, data collection, data analysis, final revision

CONFLICT OF INTEREST

None to declare.

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