Discobolul – *Physical Education, Sport and Kinetotherapy Journal*, Volume 60, Issue 4, 364-377

GLUCOSE MONITORING FOR TYPE 1 DIABETES MELLITUS IN JUNIOR RHYTHMIC GYMNASTICS – A CASE REPORT

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https://doi.org/10.35189/dpeskj.2021.60.4.1

Abstract. *The main challenge in managing type 1 diabetes mellitus is to achieve the glycaemic targets, especially when top-level athletes are involved. The present paper aims at identifying the daily continuous glycaemic oscillations that occur on a regular basis during rhythmic gymnastics training sessions. This is a case report of a 12-year-old junior rhythmic gymnast diagnosed with type 1 diabetes mellitus, with 6 years of experience in sport. Her glycaemic records were available for analysis through the FreeStyle Libre glucose monitoring sensor. The investigation took place in Bucharest between March 30 and April 26, 2021. During this time, the gymnast attended training sessions, provided that her glycaemic values allowed her to perform physical exercise. Data resulting from the LibreView specific software were correlated with the exercise parameters. From the diabetes management standpoint, it was emphasised the distribution of glycaemic values (in range, above and below the target zone) in bi-monthly and daily reports to identify the glucose profiles on training and non-training days. Depending on glycaemic oscillations, the coach adjusted in real time the training load for the athlete so that hypo- and hyperglycaemic episodes are avoided. Glucose monitoring could safely establish risk-free time intervals for both health and training purposes.*

Keywords: *flash glucose monitoring, sports performance, diabetes management.*

Introduction

Managing juvenile Type 1 Diabetes Mellitus (T1DM) has been an international research topic due to its increased incidence and repercussions upon public health. Worldwide estimates reveal that more than 98,000 children under 15 years are diagnosed every year with T1DM. Globally, there are almost 600,900 children suffering from this chronic disease (Patterson et al., 2019). Although the incidence rate widely varies across countries, it is known that, in Europe, Finland is situated first, with more than 40 cases per 100,000/year (Santi et al., 2019), while in Asia, India recorded the highest value with 0.1-8 per 100,000/ year (Chiang et al., 2014).

Diagnosed on the basis of blood sugar measurements and specific symptoms such as impaired state of health, weight loss, polydipsia or polyuria, T1DM is an autoimmune condition of uncertain aetiology, requiring lifelong insulin therapy, glucose monitoring, nutritional education, physical exercise and psycho-social care (Ziegler & Neu, 2018). The autoimmune character of this disease is proven by the specific auto-antibodies that attack the islet cells, producing their destruction (Atkinson & Eisenbarth, 2001). Moreover, this autoimmune dysfunction has the potential to produce other organ-specific or nonspecific autoimmune diseases such as thyroid, celiac and gastric conditions (Kakleas et al., 2015).

Usually, once diagnosed, the child is immediately referred to a diabetologist with paediatric experience or to a paediatrician with diabetes experience. The specialist will establish treatment goals regarding the target HbA1c, namely the best indicator of the metabolic control in T1DM, expressing the average blood glucose concentration in the last 2-3 months. Concretely, the standards refer to less than 7.5% or even less than 7% for HbA1c, when telemedicine devices are used (Miller et al., 2015). Besides HbA1c, another widely used relevant parameter in diabetes management is the time in normoglycemia, namely Time in Range (TIR), which is 70-180 mg/dl, the equivalent of 3.9-8.9 mmol/l. Specialists state that a glucose level above 250 mg/dl prior to exercise should postpone any physical activity unless urine ketones are checked. If the level exceeds 300 mg/dl, physical exercise is completely banned (Shugart et al., 2010).

In order to accurately identify daily glycaemia oscillations, children and adolescents have to measure their blood sugar 5-6 times per day or even more (Ziegler et al., 2011). According to these values, prandial analogues and basal insulin will cover mealtimes and adjust high glucose values in an individualised pattern (Cemeroglu et al., 2013). Traditionally, insulin therapy is delivered either intravenous, in ketoacidosis treatment, or using an insulin pen.

Latest technologies developed in the area of telemedicine have provided more accurate and less invasive procedures for insulin therapy delivery and optimal glucose control. Thus, insulin pump therapy consists in the administration of treatment according to the needs of the child, including boluses for mealtimes and adjustments of high glucose levels. From the circadian rhythm perspective, insulin secretion is lower at night and higher during morning, which is known as “the dawn phenomenon” (Porcellati et al., 2013). In this context, cohort studies show that insulin pumps lead to an overall metabolic improvement through less frequent hypoglycaemic episodes and prevention of hyperglycaemia during morning (Karges et al., 2017). The interstitial glucose concentration is measured every 3-5 minutes through continuous glucose monitoring (CGM) systems by means of a subcutaneous sensor, the values being transmitted to a receiver. Another technical solution is represented by flash glucose monitoring (FGM) that allows to detect glycaemic values only when the receiver scans the sensor in its proximity (Ly et al., 2013). According to numerous studies (Ziegler et al., 2016; Ly et al., 2013; Karges et al., 2017), CGM systems allow children to access bloodless sugar measurements to minimise the frequency of hypoglycaemic episodes, thus becoming less dependent on their parents and more likely to fully enjoy a good quality of life.

Medical treatment should be complemented in the long term by the child’s commitment to an active lifestyle, including regular physical exercise as part of the diabetes education. This endeavour should be supported by a multidisciplinary team consisting of physicians, parents, educators and peers in order to formulate consensual goals for proper diabetes management.

Studies (Yardley at al., 2013; Marliss & Vranic, 2002) emphasise that physical exercise may lead to either hypo- or hyperglycaemia, depending on the training load and the hormone regulatory particularities. Very often, fear of exercise-induced hypoglycaemia perceived by both children and parents is the main roadblock to participation in regular physical activity (Roberts et al., 2020). This occurs especially when T1DM children are not appropriately monitored, in terms of glucose and insulin adjustments, prior, during and post-exercise (Roberts et al., 2017).

Although fear of hypoglycaemia (FOH) is the main barrier to performing physical activity, excessive FOH can lead to opposite negative metabolic consequences such as hyperglycaemia, low glycaemic control and maladaptation to an autonomous lifestyle (Johnson et al., 2013; Gonder-Frederick et al., 2011). A cross-sectional study (Beraki et al., 2014) based on a diabetes quality registry in Sweden aimed at assessing possible associations between physical exercise and HbA1c within a large group of 7-18-year-old patients. The most relevant results emphasised the following aspects: the least physically active participants had higher mean HbA1c levels than the most physically active ones; a negative correlation was found between HbA1c and physical activity for both genders and age groups, except for girls aged 7-10 years; boys were slightly more active compared to girls.

Based on these arguments, practising high-level sports is not considered an unrealistic option, provided that the whole training process meets the requirements for risk-free participation of the T1DM child. This goal becomes attainable through long-term cooperation between athletes, parents, technical and medical staff. According to evidence, the sports activities performed by T1DM children and adolescents range from leisure physical activities to Olympic participation (Harris & White, 2012). Either way, exercise is based on anaerobic or aerobic energy sources (Riddell & Iscoe, 2006). Specifically, most gymnastics events access the anaerobic lactic energy pathway, which is characterised by high intensities, explosive power from ATP and CP, specific endurance due to glycolysis, production of lactic acid and duration of maximum 90 seconds, according to the time limit of the routines (Sands et al., 2001). Nonetheless, each training session or competition event requires many hours, which triggers aerobic energy systems as well. Overall, exercise is determined by complex physiological factors such as insulin, glucagon, cortisol and catecholamines and growth hormones, their ratio depending on the exercise intensity and duration (Camacho et al., 2005). Thus, in low-moderate intensity, the energy resource is mostly represented by plasma-derived free fat acids, while during heavy exercise, the carbohydrate use may reach 1-1.5 g/kg/hour in adolescents with diabetes (Riddell et al., 2000). Within an intensive workout, catecholamines are triggered, which increases the release of liver glucose, free fat acids and the ketone levels while diminishing the use of glucose by muscles; consequently, anaerobic exercise leads to hyperglycaemia for T1DM athletes, even under insulin therapy (Ridel et al., 2017).

As research has brought evidence of the metabolic control in diabetes pathology, authors have proven the possibility to engage T1DM children and adolescents in sports training due to both the physiological and psychological benefits perceived by competitors (Harris & White, 2012). In this context, the sports literature emphasises numerous T1DM athletes competing in football, basketball, handball, cycling, soccer, ice hockey, rowing, softball, swimming, tennis, taekwondo, winter sports, etc.

This study aimed at presenting a way to integrate glycaemia monitoring for a T1DM rhythmic gymnast within the training process. Based on a case report, this investigation started from the following research questions: what is the glucose profile that allows the gymnast to perform during the training session? are there optimal measures to be taken by the coach in real time so that the risk of hypo- or hyperglycaemia is avoided?

Case report

Participant

The gymnast analysed in this study was a 14-year-old girl with 9 years of experience in rhythmic gymnastics. Her best sports results included several national titles with the team as well as finals qualifications in individual events. In October 2018, she was diagnosed with T1DM, being provided with a glycaemia monitoring system from the onset of the disease. Her diabetes management included 17 units basal insulin and 8 to 12 units prandial insulin administered before or after meals, depending on her glucose values, along with a nutritional diet and physical activity. The patient used to correct hyperglycaemic spikes with 2 units of rapid analogue. She attended 8 training sessions of 2 hours 30 min each during the analysed period.

In the last 3 years, her diabetes was closely monitored by a diabetologist, including regular HbA1c checks that gave information about her average blood glucose levels over a 3-month period. At present, she uses a FreeStyle Libre sensor-based glucose monitoring device. The research protocol met the requirements of the Declaration of Helsinki regarding human participants. Her parents signed the informed consent. Data were anonymised.

Procedure

The gymnast's weight and height were assessed using a digital scale and a standard stadiometer. Body mass index (BMI) was also determined and analysed on percentile charts.

A one-month period of glucose monitoring was trimmed from the FreeStyle Libre continuous streaming data and analysed in conjunction with the sports training content. This device allows glucose monitoring on the gymnast's reader by scanning her sensor with a specific LibreView application.

The FreeStyle Libre is a FGM system comprising a sensor attached to the upper part of the arm, which continuously captures the glucose concentration within the subcutaneous interstitial fluid and displays a new value every 5 minutes by means of a thin filament puncturing the skin; a reader that scans the sensors allows data collection. Every 14 days, the sensor needs to be replaced, being a consumable item. The FGM is considered as a hybrid between the finger prick blood glucose measurements and the CGM systems (diaTribe Foundation, 2021; Naaraayan et al., 2018). Overall, the advantage of using the FGM for a child resides in a lower number of daily finger pricks and thus a less traumatising T1DM management. Nonetheless, when there are suspicions about the glucose level readings, finger pricks are required because accurate data are mandatory. Three types of information are available via FGM: the current glucose level, the trend of glucose oscillations, the last 8 hours of recordings. Data are processed with the LibreView application that provides periodical ambulatory glucose profile (AGP) curves as well as AGP reports. These included four glucose ranges highlighted in different colours, namely low glucose level < 70 mg/dl (red), target zone level 70-180 mg/dl (green), above target level 180-250 mg/dl (yellow) and very high glucose levels > 250 mg/dl (orange). Data from the AGP reports are processed by the LibreView software, glycaemia values being processed and converted in different graphs, as if occurring in a single day. A relevant parameter provided by the software is the Glucose Management Indicator (GMI), which is more or less an equivalent of the HbA1c.

For this research, two AGP reports were analysed per 14 days, from March 30 to April 26, highlighting the differences between training and non-training days, in terms of glucose control. During this period, the training contents, the gymnast's symptoms and the counter measures applied by the coach were also analysed. In order to identify the exercise loads producing hyper- or hypoglycaemia, observational files were completed during the training sessions. In this respect, a Zephyr device was available for assessing punctual heart rate and thus the corresponding exercise intensities. The point values of the heart rate in different moments of the training sessions were extracted separately from the HRV analysis, which is the main parameter assessed using the Zephyr device.

Results

Anthropometric measurements

The gymnast weighted 58 kg and her height was 160 cm. The calculated BMI was 22.65 hg/m^2 corresponding to healthy weight category. Regarding the growth percentile charts, her BMI fell between 75 and 85 percentiles. The girl experienced menarche at 13 years old.

Glucose monitoring synthesis

Figure 1 shows the monthly summary of average glucose levels, the number of daily scans and the extreme (low or high) values, if present. One can notice that, in the 13 days of the analysed period, glycaemia recorded values under 250 mg/dl. In the rest of the days, glucose levels exceeded 250 mg/dl, with the pick values highlighted in orange. No hypoglycaemia events were recorded during this month. In terms of number of scans per day, the gymnast checked her glucose sensor less than 10 times/day, only in 6 of the 28 days of monitoring, proving good compliance with this task.

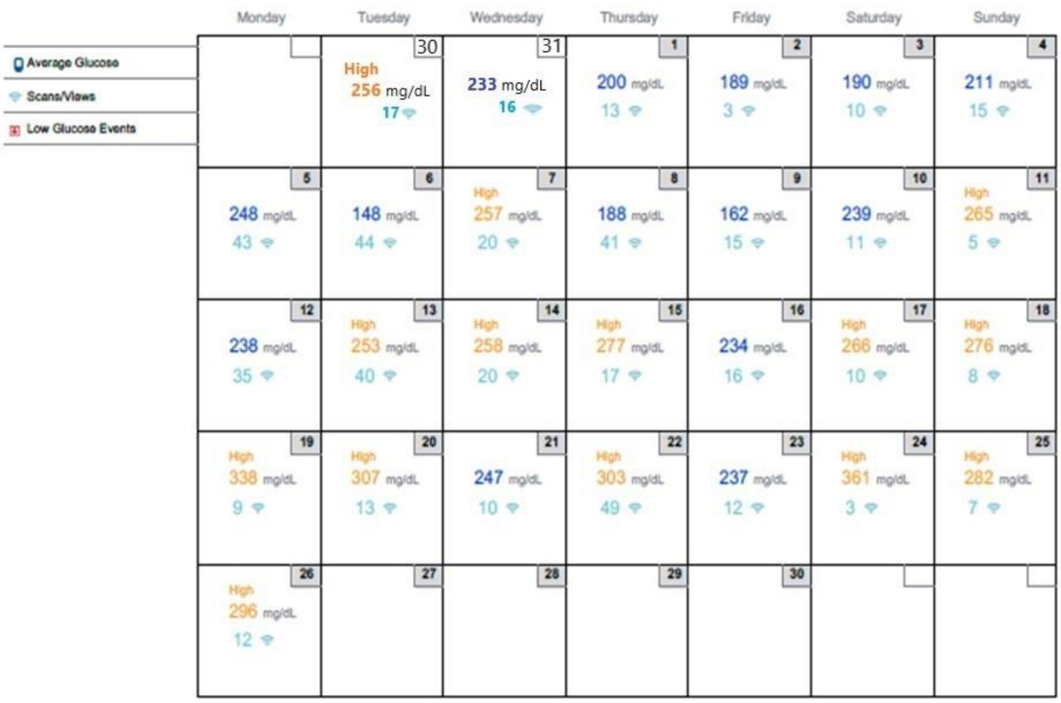

Figure 1. Monthly summary (March 30 - April 26)

The glucose average value for the first 14 days was 217 mg/dl, while the similar parameter for the second period was 280 mg/dl. In terms of GMI, the gymnast recorded a value of 8.5% for the first 14 days and a value of 10% for the second period.

Figure 2 indicates relevant data for diabetes management regarding the glucose levels with reference to the target range and their duration in the first 14 days of monitoring. The gymnast succeeded to stay in the target range only 32%. The time spent in very high levels was 31%, the time spent in high levels was 37% and no time was spent in low or very low glycaemia values. (Figure 2.a) In the next 14 days, the gymnast managed to stay in the target range only 13% of the total time. The time spent in very high levels was 63%, while the time spent in high levels was 24%. No time was spent in low or very low values. (Figure 2.b)

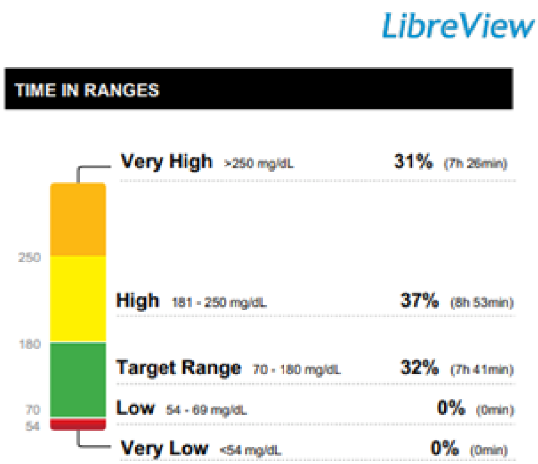

Figure 2.a. AGP report for March 30 - April 12

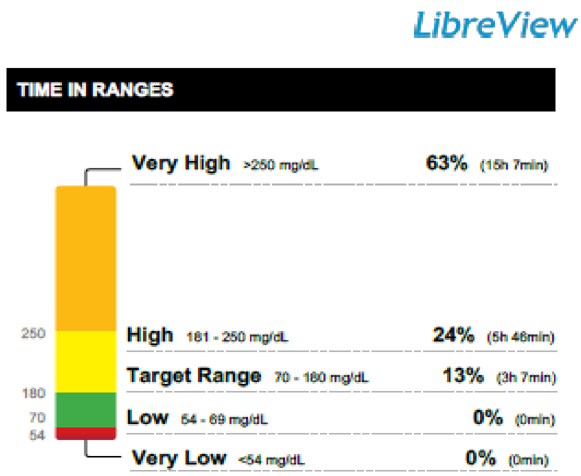

Figure 2.b. AGP report for April 13 - 26

The AGPs illustrated in Figure 3 and Figure 4 give relevant data about both the median as a statistical cue for the recorded range of values and the trends of hypo- or hyperglycaemia. The software provides a statistical analysis for the measures of central tendency (median and mean) and the inter-quartile range (IQR) variability as shown in the figures below. The gymnast's data are analysed according to reference values incorporated in a percentile system. Therefore, the median value differs depending on the moment of the day and falls within the 50th percentile, which is situated between the inter-quartile range. This IQR characterises the variability of value distribution between the 75th and the 25th percentile. Fifty percent of glucose values fall within the inter-quartile range, 25% of them fall above the 75th percentile, while the rest fall below the 25th percentile. In the first 14-day report, the median had lower values between 3 and 6 a.m. (within the target range), which progressively raised, reaching the highest values between 9 a.m. and 2 p.m. The median curve decreased until 5 p.m. and recorded increased values again between 7 and 11 p.m. (Figure 3)

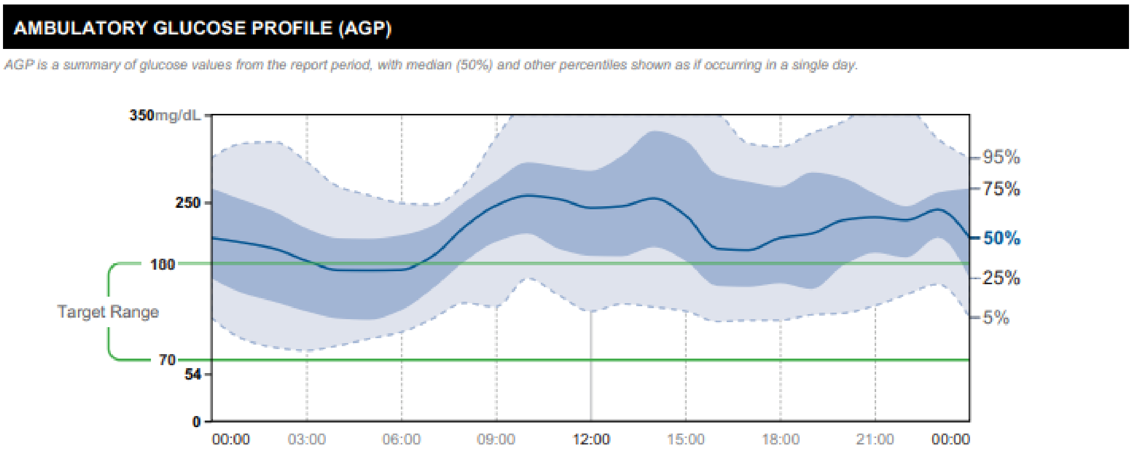

Figure 3. AGP curves for March 30 - April 12

In the next 14 days, the median had lower values between 4 and 7 a.m., which progressively raised, reaching a pick value at 11 a.m., followed by a small decrease until 1 p.m. Afterwards, the values described a high plateau with small glycaemia oscillations until 12 p.m. All median values exceeded the target range, falling within 250-300 mg/dl. (Figure 4) All these data show poor metabolic control.

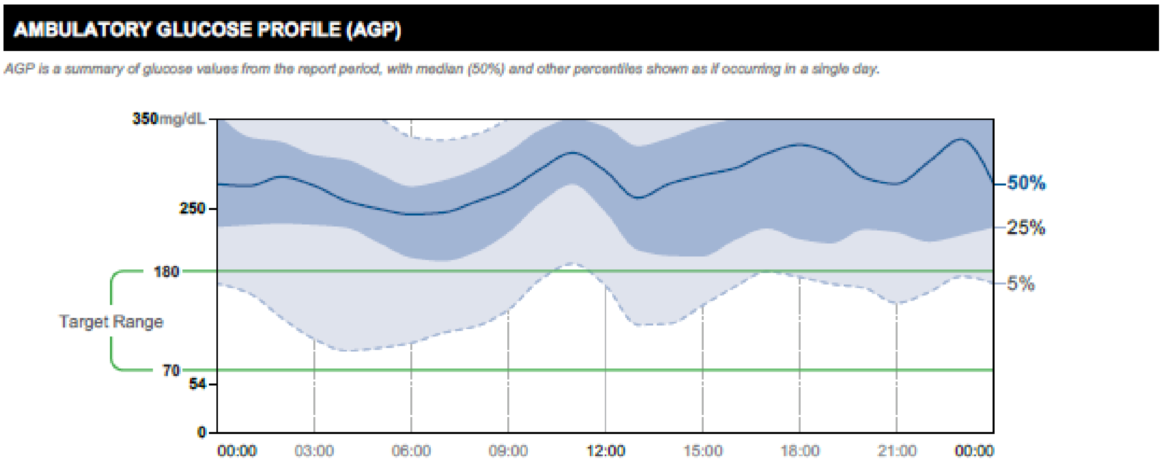

Figure 4. AGP curves for April 13 - 26

The following daily logs emphasise the scanned values during two training days with a very different glucose profile and thus with repercussions upon the training content. In both situations, the training sessions began at 11 a.m. and ended at 1.30 p.m.

Figure 5 shows that the gymnast started the first analysed training with a glucose value of 173 mg/dl. Consecutive scans revealed glucose levels within the target range throughout all training sessions, the lowest value being 117 mg/dl and the highest value, 157 mg/dl.

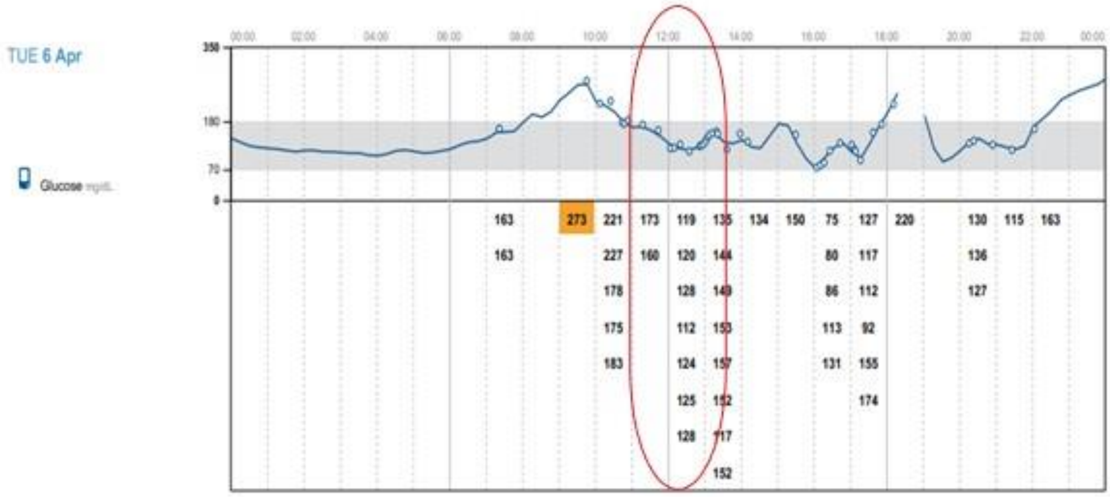

Figure 5. First training session recording

The second training session included in this case report exhibited a totally different glycaemia profile compared to the first lesson analysed (Figure 6). Due to a basal glycaemia value of 281 mg/dl at the beginning of the session, the gymnast was unable to fulfil the training tasks. Multiple scans revealed a hyperglycaemia status during the whole training sequences. Out of the 26 glucose measurements taken during the session, only 6 exhibited values that normally allow the gymnast to perform physical exercise. The rest of the values exceeding this limit exposed the gymnast to ketosis, and thus the coach decided to interrupt.

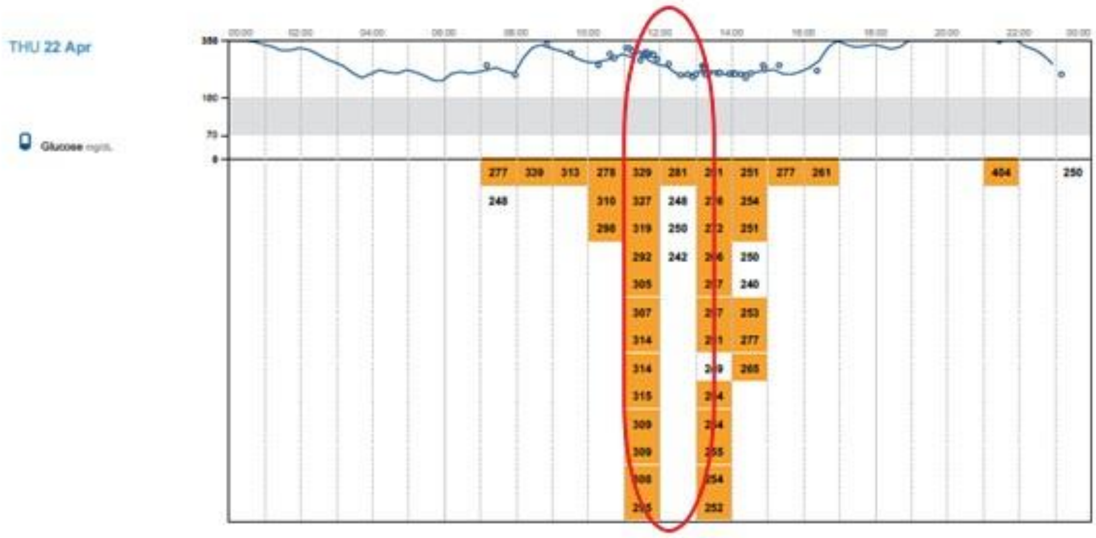

Figure 6. Second training session recording

Training content analysis related to glucose oscillations

Certain synchronised aspects related to the training load and its consequences on glucose values during the training session performed on April 6 are presented in Table 1.

Table 1. *Training content analysis and glucose oscillations*

Training contents	Duration	Average HR (beats per minute)	Glucose level mg/dl	Carbohydrate intake
Warm-up	47 min	116	173	0
- dynamic exercises	3 min	158	173	0
- analytical exercises without displacement	5 min	136	173 – 160	0
- ballistic exercises using the ballet barre	10 min	135	160	0
- splits	15 min	124	119 – 120	+ 50 ml orange juice
- technical jumps	4 min	172	128	0
- pirouettes	10 min	139	112	+ 50 ml orange juice
- Specific warm-up: ball	20 min	147	112 – 124	0
- Half-routines ball	10 min	153	124 – 125	0
- Break	10 min	134	125	0
- Whole routines: ball	1 min 30 sec	161	128	0
- break	10 min	138	135	0
- Whole routines: ball	1 min 30 sec	174	144	0
- Break	10 min	129	149	0
- element reps	10 min	147	153	0
- Physical preparation	20 min	145	157	0
- Cool down	10 min	105	152	0

According to the American College of Sports Medicine (Paternostro Bayles & Swank, 2018), the exercise intensity can be analysed according to the five heart rate zones and the individual maximal heart rate. As shown in Table 1, the gymnast had an average HR of 144 beats per minute (bpm) but also relevant variations depending on the sequences of the lesson. Specifically, she started the warm-up with a HR value of 116 bpm, which increased up to 158 bpm after the dynamic exercises, thus entering the heavy intensity effort zone. During analytical exercises without displacement, the HR decreased up to 136 bpm, corresponding to the moderate effort zone.

Ballistic exercises were performed in the same effort zone, followed by split flexibility exercises that lowered the parameter up to 124 bpm, corresponding to the light intensity zone. The dynamic sequence of technical jumps raised the HR to an average of 172 bpm, namely up to the very heavy intensity zone. Pirouette repetitions brought the HR to 139 bpm, in the moderate effort zone. The use of apparatus combined with body elements during the ball-specific warm-up raised the HR to 147 bpm, corresponding to the heavy effort zone. The two half routines were performed by the gymnast within the heavy effort zone, with 153 bpm. As expected, the two ball routines led to highest average heart rates (161 bpm and 174 bpm), which were consistent with the very heavy effort zone. During the breaks between the routines, the incomplete recovery lowered the HR values up 138 bpm and 129 bpm, respectively. The final part of the training session where strength exercises were performed for 20 minutes led to an increase in HR up to 145 bpm, corresponding to the moderate intensity zone. The cool-down lasted 10 minutes during which the HR lowered to 105 bpm.

During the lesson, following the multiple glycaemia scans, there were two moments when the gymnast needed carbohydrate intake due to the level of glucose delivered by the FreeStyle sensor - 119 mg/dl and 112 mg/dl. The recorded glycaemia values required no training content adjustments from the coach, the glucose level falling within the target range. The gymnast did not experience relevant symptoms of hypoglycaemia.

Discussion

Analysis of the monthly summary regarding glycaemia values lead to the idea that the gymnast has not managed to find proper metabolic control, which is probably related to the puberty stage characteristics. Actually, studies have stressed the importance of tackling diabetes challenges in child development (Streisand & Monaghan, 2014) in order to prevent hypo- or hyperglycaemia events.

As a consequence, most of the days included in the report exhibited hyperglycaemia values and insufficient time spent in the range, namely almost 22% of the total period compared to the guideline reference, which is 70% (Battelino et al., 2019). With respect to the glycaemia management indicator, the gymnast’s values exceeded the reference value of 7% during the monitored period, this proving once again her low ability to keep glycaemia values in the target range, especially in this critical developmental stage.

This case report has revealed that the participant is predominantly hyperglycaemic, even though her biggest concern is related to the constant fear of hypoglycaemia. This primary concern could be explained by the fact that the symptoms in hyperglycaemia events are not perceived by the child with the same intensity as the hypoglycaemia values. The number of scans per day could probably reflect the same fear of hypoglycaemia. Thus, the child is likely to develop specific severe medical complications in the long term (Katsarou et al., 2017).

Very often, the gymnast had difficulty managing the glucose homeostasis, which exposed her to compromise the training sessions and lose her preparation level. Under these circumstances, her training objectives were adjusted by the coach to her present capabilities. Despite the T1DM, studies have revealed that high-level athletes can embark in sports training with normal loads as long as their blood glucose is properly controlled (Shugart et al., 2010).

Glucose values monitored from the first lesson were perceived by the gymnast as threatening for a possible hypoglycaemia event, but even though, these levels were in the target range. Therefore, she usually had carbohydrate intakes to maintain the level at the upper range limit. This tendency is clearly acknowledged in the literature for training sessions longer than one hour, the amount of carbs depending on the exercise intensity (Grimm et al., 2004).

Also, glycaemia during training was not necessarily influenced by the exercise intensity, as we supposed. Obviously, further measurements and monitoring are needed to address a possible statistical correlation between glycaemia and specific training load.

On the other hand, glycaemia values in the second lesson, which were noticed by the coach on the receiver of the glucose sensor, as well as the gymnast's symptoms, led to the common attempt to adjust the training load and initially engage in exercise. Still, the glycaemia control was impossible to achieve despite the long resting breaks, so the training session had to be ended.

In short, this case report has demonstrated that performing a training session necessarily requires from the very beginning a glycaemia value within the target range, which gives some space for this parameter to slightly oscillate without putting the gymnast in danger. In the long run, the H1AbC value should be around 7%, this medical cue illustrating good diabetes management and thus the athlete's capability to perform.

Limitations

The main limitation of this study was the length of the monitored period, which precluded drawing general assertions.

No previous data regarding the gymnast's glycaemia values were taken into consideration due to the difficulties reported by the family to access the LibreView application.

Conclusion

Medical records and glucose monitoring reports have emphasised that the participant's clinical condition clearly requires adjustments in diabetes management. This is a mandatory intervention for the gymnast to overcome glycaemia oscillations triggered by the puberty stage.

Conducting a training lesson with a T1DM athlete is a true challenge for any coach in terms of being aware of the specific characteristics of this metabolic disorder and adjusting in real time the training content so that a balance between the training objectives and the health status should be achieved in the long term. This strategy should be convergent with insulin therapy, nutritional recommendations and a lifelong health education.

Although physical exercise has often proven to be beneficial for diabetes management, glucose control is essential for initiating or continuing risk-free sports training.

On a positive note, the presence of T1DM in children and youth should not hinder their quality of life and prevent them from fully enjoying sports training and competitions, provided that a joint effort of the child's family, diabetologist, coach, educators and peers is available.

Authors' Contributions

All authors have equally contributed to this paper and should be considered as main authors.

Acknowledgement

Authors would like to address sincere thanks to the gymnast and her family for their cooperation during this research.

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